PB-230 604

WATER RESOURCES ACTIVITIES IN THE UNITED STATES. ELECTRIC POWER IN RELATION TO THE NATION'S WATER RESOURCES

Select Committee on National Water Resources,
U. S. Senate

January 1960

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86th Congress
2d Session

COMMITTEE PRINT NO. 10

WATER RESOURCES ACTIVITIES
IN THE
UNITED STATES

ELECTRIC POWER IN RELATION TO THE NATION'S WATER RESOURCES

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SELECT COMMITTEE ON NATIONAL WATER RESOURCES
UNITED STATES SENATE

PURSUANT TO

S. Res. 48

EIGHTY-SIXTH CONGRESS

JANUARY 1960

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U S Department of Commerce
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Printed for the use of the Select Committee on National Water Resources

UNITED STATES
GOVERNMENT PRINTING OFFICE
50504
WASHINGTON : 1960

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(Pursuant to S. Res. 48, 86th Cong.)

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STATEMENT BY THE CHAIRMAN

JANUARY 22, 1960.

To the Members of the Select Committee on National Water Resources:

What will be the demands for electric energy in 1980 and beyond? To what extent will these demands be met by hydroelectric or nuclear powerplants and by steam or internal combustion plants? What will be the water requirements for cooling purposes? What is our water power potential in relation to anticipated demands for power? Answers to these and other questions will be essential to our committee in its study of water problems and requirements under the provisions of Senate Resolution 48.

In order to take advantage of information relating to these problems available from different sources, I asked the Federal Power Commission, the Rural Electrification Administration of the Department of Agriculture, the American Public Power Association, and the Edison Electric Institute to report to the committee as to their views with respect to the questions stated above. I was also able to take advantage for the committee of studies of the future of hydroelectric power in the American economy being made by members of the staff of the Resources for the Future, Inc., a nonprofit corporation financed by grants from the Ford Foundation. All of these reports have now been received. They contain a wealth of information, and space permits only a few of the many facts to be highlighted herein.

The Federal Power Commission anticipates that the Nation's power industry will have peak loads in 1980 of 389 million kilowatts as compared with 134 million kilowatts in 1958, and an annual per capita energy requirement of 8,000 kilowatt-hours in 1980, and about 10,500 kilowatt-hours in the year 2000, compared with 1958 requirements of 4,183 kilowatt-hours. Hydroelectric power capacity is expected to more than double by 1980, increasing from 30 million kilowatts to over 64 million kilowatts, and generator capacity in steamplants is expected to more than triple with an increase from 127 million kilowatts in 1958, to 379 million kilowatts in 1980.

Projections by the Edison Electric Institute indicate that by 1980, peak loads of the electric industry will reach 501 million kilowatts compared with 129 million in 1959. Total energy requirements for the United States are expected to increase from 4,481 kilowatt-hours per capita in 1959, to about 11,800 in 1980, and to between 17,600 to 29,400 kilowatt-hours in the year 2000. Hydroelectric power capability of the investor-owned utility systems is expected to double by 1980, reaching 25 million kilowatts from 12½ million in 1959. The bulk of power requirements in 1980 are estimated to be met from conventional steam electric plants, the total capability of which is expected to quadruple from 112 million kilowatts in 1959 to 417 million in 1980.

As to nuclear-fueled powerplants the Edison Electric Institute reports that 131 investor-owned utilities are presently participating in the study, design, construction, and operation of nuclear plants having an ultimate capacity of 1,400,000 kilowatts. Projections to 1980 indicate the possibility that about 39 million kilowatts of nuclear capability will be serving loads of investor-owned systems.

During 1959 about 26,813 billion gallons of water were circulated in thermal plants of investor-owned systems. By 1980 this amount is estimated to increase to 106,409 billion gallons yearly. The Federal Power Commission estimates that circulating water in all thermal plants in 1980 will total approximately 290 million acre-feet or about 95,000 billion gallons. Fortunately from the viewpoint of national water supplies less than 1 percent of this cooling water, that portion evaporated in cooling towers or ponds, is actually a consumptive use.

The Department of Agriculture advised us that in 1958, the installed capacity in plants financed by Rural Electrification Administration loans was 1,195,485 kilowatts, which supplied 15 percent of the total energy requirements of REA borrowers. Using this same percentage, REA estimates that installed capacity in its borrower-owned generating plants will be 6 million kilowatts by 1980.

The Department expects that most of the increased capacity shown will be installed in steamplants. It is also estimated that by 1980 nuclear-fueled plants may account for 15 to 25 percent of the total installed steamplant capacity owned by REA borrowers.

The American Public Power Association makes no projections of future energy requirements but points out what appears to the association to have been fundamental weaknesses in earlier power requirements forecasting.

The report by the staff of Resources for the Future indicates that present hydropower capacity represents between one-quarter and one-third of our actual and economic water power potential and that the overall resource limitation on hydro development in the United States is not yet within sight, because there will be improvements in technology which cannot be foreseen on the basis of our present knowledge. Further improvements in technology should largely offset any tendency toward increase in cost of hydropower development, and if our installed hydro capacity does not continue to grow at a rapid rate, it will be because of such factors as adverse governmental policy, high interest rates, or a slowdown in the regional growth in demand.

As was expected, the reports reveal numerous differences of opinion as to the nature of the growth of the electric power industry, and, if the past is taken as a guide, the actual growth may well exceed even the most liberal of the forecasts.

The information contained in the five reports will be of interest to the committee, to other Members of the Senate, and to all interested in the future of our power industry, and the water requirements of the industry. Accordingly, I am having them printed as one of our committee prints dealing with the various aspects of water resource activities.

Rob'T S. Kerr,
Chairman, Select Committee on
National Water Resources.

COMMUNICATIONS

JUNE 16, 1959.

Mr. JEROME K. KUYKENDALL,
Chairman, Federal Power Commission,
Washington, D.C.

MY DEAR MR. CHAIRMAN: Enclosed is a copy of Senate Resolution 48, adopted April 20, 1959. Under its provisions a committee composed of Senators from each of the Committees on Interior and Insular Affairs, Public Works, Interstate and Foreign Commerce, and Agriculture and Forestry, has been established, and steps are being taken to assemble and analyze information concerning the many complex phases of the Nation's water problems.

Under the provisions of the resolution the committee is directed to make full use of the information collected and compiled by the executive agencies and the agencies are requested to give such assistance as may be required. In this connection, the fund of information available in the Federal Power Commission relating to the fields of hydroelectric power, electric energy needs, use of water for cooling purposes in steam electric generating plants, and other related matters, will be of great value to the committee's studies.

As one of the first steps, the committee would like to have information along the following general lines:

1. Electric energy demands, and capacity requirements by region, at present and projected to 1970 and 1980. To expedite the work the regions may conform with areas or regions now used by the Commission. Breakdown to show extent to which demands are met and are anticipated to be met by hydro, thermal, or other source, including nuclear energy.

2. Estimates of per capita electric energy demands for the United States at present and in 1970, 1980, and 2000.
   - (*a*) Household and farm.
   - (*b*) Industrial and municipal.
   - (*c*) All other.

(Breakdown to depend on breakdown used by the Commission.)

3. Anticipated possible means of adding capacity 1970 and 1980, by region (as 1 above) with costs of production for each broken down to the extent possible into capital charges, fuel, maintenance, etc., and information as to water requirements.

4. Estimated amounts of primary and secondary hydropower available in 1970 and 1980, by regions, assuming capacity increments as in 3 above.

5. General comments by the Federal Power Commission on trends in the production of electric energy, on the power requirements of the Nation and means by which they can best be met, water requirements for hydropower and for cooling, and other matters which the Commission believes may be of value to the committee in its consideration of the Nation's water problems.

We would like this information to be made available, if possible, in a summary report of not more than about 10,000 words, with whatever tables, charts, appendixes, and graphic illustrations as may be considered necessary. It would be most helpful if this information could be furnished to the committee by October 1, 1959.

The committee has set up a small staff of which Mr. Theodore M. Schad is director. From time to time he, or members of his staff, may wish to confer informally with members of your staff. It would be helpful to us if you would designate a staff member to serve as a liaison officer with the committee staff in working out the details of the study.

We would appreciate hearing from you as soon as possible.

Sincerely yours,

ROB'T S. KERR, *Chairman.*

FEDERAL POWER COMMISSION,
Washington, November 2, 1959.

Hon. ROBERT S. KERR,
Chairman, Select Committee on National Water Resources,
U.S. Senate, Washington, D.C.

DEAR MR. CHAIRMAN: With regard to Senate Resolution 48, the staff of the Federal Power Commission has completed a report containing the information requested in your letter of June 16.

In connection with this report our staff has had several conferences with Mr. Schad and other members of your committee staff. It is regretted that we were unable to complete our report by October 1, but trust that this has not delayed your study on the Nation's water problems. Mr. Adams, Chief of our Bureau of Power, explained to Mr. Schad that it was necessary for us to prepare material for the Senate Joint Economic Committee in connection with hearings recently held by its Subcommittee on Automation and Energy Resources, and Mr. Schad agreed that inasmuch as field hearings were being held by the Select Committee on National Water Resources, a delay in our report would cause no inconvenience.

Your original request of June 16 stated that the information to be supplied by the Federal Power Commission should conform with the regions now in use by the Commission in order to expedite the work. Thus, the data we are supplying at this time relate to what we term "power supply regions," and eight of these regions cover the United States exclusive of Alaska and Hawaii. The Federal Power Commission regions are subdivisions which we utilize in electric power supply and requirements work. The regions comprise electric utility systems which are sufficiently interconnected to consider them as belonging to a group in the analysis of power problems, and the Commission's records and publications on electric power are compiled in conformance with these regional boundaries.

Your committee is now assembling material on the basis of 22 water resource regions covering the United States, and these regions for the most part are delineated on the basis of river basins. It is our understanding that the data we are supplying herewith on a power supply region basis are adequate for the needs of your committee except with respect to water requirements of steam-electric and hydroelectric plants. One of the tables included in our report contains water use information for our power supply regions. In accordance with discussions with your staff, however, we are proceeding to analyse the water requirements of the 22 water resource regions being utilized in your investigation. This phase of the study will require a considerable amount of time and we plan to explore your needs more fully in this respect in order to make the material more useful to your study and in order to devise possible shortcut procedures to expedite the work. Inasmuch as we do not compile information on the basis of 22 water resource regions, a considerable amount of tabulating work will be necessary. We have completed preliminary studies of the water requirements of the Ohio River region and the upper Rio Grande and Pecos River region as requested by your staff. The latter data are not included herewith and will be held in abeyance pending further discussions with your staff.

Our report as transmitted herewith consists of six tables which answer the specific questions raised in your letter of June 16. Data for 1970 are omitted as suggested by your staff. The text included in the report explains how the figures in these tables were obtained, clarifies the information, and sets forth its limitations.

We, of course, shall be glad to discuss this report with your staff and cooperate with them in other aspects of your program to investigate the Nation's water problems.

Sincerely yours,

JEROME K. KUYKENDALL, *Chairman.*

Enclosure No. 44934, report, with map showing power supply regions.

CONTENTS

Page

Statement by the chairman ... III

Communications ... v

Federal Power Commission report ... 1

- Table 1. Peakloads ... 1
- Table 2. Year-end installed electric generating capacity ... 3
- Table 3. Electric energy requirements of the United States ... 4
- Table 4. Electric utility costs in 1980 ... 4
- Table 5. Water requirements of electric utilities in 1980 ... 5
- Table 6. Electric utility 1980 energy requirements ... 6

Letter of June 23, 1959, to Edison Electric Institute ... 9

Edison Electric Institute letter and substantiating report ... 10

- Map 1. Power supply regions as defined by the Federal Power Commission ... 14
- Substantiating Report ... 15
  - I. Peakload, capability, and energy requirement forecasts ... 15
    - Chart I. U.S. total electric utility industry, electric energy generation ... 16
    - Table I. Peakload, capability, and energy requirements, total United States ... 17
    - Table II. Energy use per capita, total United States ... 17
    - Table III. Peakloads and energy requirements, total electric utility industry ... 18
    - Table IV. Capability types used to supply total electric utility industry load ... 18
    - Table V. Capability types used to supply investor-owned system loads, 1959, 1970, and 1980 ... 23
  - II. Production costs of conventional thermal plants ... 23
  - III. Nuclear power ... 28
  - IV. Hydro development ... 29
    - Table VI. Hydro capacity additions in megawatts, investor-owned systems ... 29
  - V. Water requirements for thermal plants ... 31
    - Table VII. Cooling water circulated in thermal plants investor-owned systems ... 32
    - Table VIII. Cooling water circulated in thermal plants investor-owned systems by FPC regions ... 32
    - Glossary of terms ... 33

American Public Power Association letter and report ... 35

- Introduction ... 35
- Forecast of future power requirements ... 36
  - Chart A. Federal Power Commission forecasts of future U.S. power needs ... 38
  - Chart B. Future electric utility generation, four projections ... 40
  - Table 1. Electricity generation in the United States ... 41
  - Chart C. Generation of electricity in the United States ... 42
  - Chart D. Indexes of total electric utility generation ... 43
- Experience of two regions ... 45
  - Chart E. Rates of growth in three sectors of U.S. power industry ... 46
  - Table 2. Growth of three sectors of the electric utility industry: 1945–58 ... 47
- Hydroelectric development: 1960–80 ... 47
  - Chart F. Sales, per customer costs and unit costs: 1950–58, TVA distributors ... 48
  - Chart G. Residential service, average use per customer ... 49
  - Table 3. Percent development of hydroelectric power resources ... 53
- The nature of future production ... 54
- The nature of future consumption ... 58
- Conclusion ... 60

Department of Agriculture letter of October 7, 1959, with projections of Rural Electrification Administration program requirements ... 61

- Table 1. Electrical energy requirements of REA borrowers ... 61
- Table 2. Electrical demands of REA borrowers ... 61

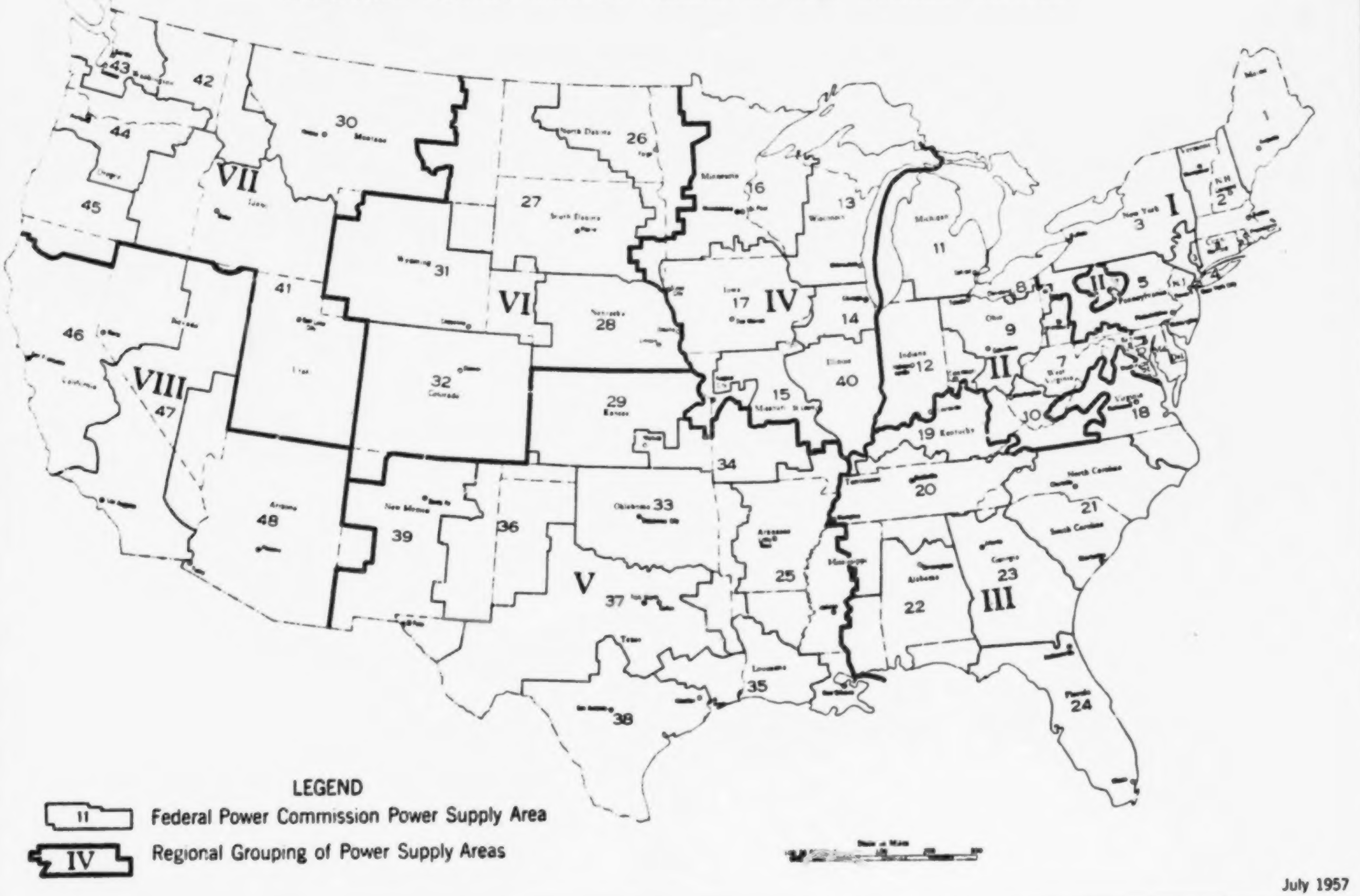
Letter to Resources for the Future, dated December 21, 1959 ... 62

Resources for the Future letter of January 7, 1960, and report on the Future of Hydropower Through 1975 ... 62

- Introduction ... 63
- The concept and measurement of hydropower resources ... 63
- Estimates of hydropower potential in the United States ... 68
- Estimates of future hydropower capacity in the United States ... 71
  - Table I. Estimates of future U.S. hydropower capacity ... 72
  - Table II. Average annual growth rates of hydropower capacity, 1925–61 ... 75
  - Table III. Regional distribution of U.S. hydropower potential ... 76
- Technology as a determinant of future hydropower development ... 76
- Conclusions ... 83

FEDERAL POWER COMMISSION

ELECTRIC POWER SUPPLY AREAS IN THE UNITED STATES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48
LEGEND
11 Federal Power Commission Power Supply Area
IV Regional Grouping of Power Supply Areas

July 1957

ELECTRIC POWER IN RELATION TO THE NATION'S WATER RESOURCES

FEDERAL POWER COMMISSION REPORT ON ELECTRIC POWER AS RELATED TO THE NATION'S WATER PROBLEM

This report has been prepared at the request of Hon. Robert S. Kerr, chairman, Select Committee on National Water Resources of the U.S. Senate. The committee, as provided in Senate Resolution 48, adopted April 20, 1959, is investigating the many complex phases of the Nation's water problems. By letter of June 16, 1959, Senator Kerr requested the Chairman of the Federal Power Commission, Jerome K. Kuykendall, to prepare a report giving the following information, as quoted from the letter:

> 1. Electric energy demands and capacity requirements by region, at present and projected to 1970 and 1980. To expedite the work the regions may conform with areas or regions now used by the Commission. Breakdown to show extent to which demands are met and are anticipated to be met by hydro, thermal, or other source, including nuclear energy.
>
> 2. Estimates of per capita electric energy demands for the United States at present and in 1970, 1980, and 2000.
>
> (*a*) Household and farm.
> (*b*) Industrial and municipal.
> (*c*) All other.
>
> (Breakdown to depend on breakdown used by the Commission.)
>
> 3. Anticipated possible means of adding capacity 1970 and 1980, by region (as 1 above) with costs of production for each, broken down to the extent possible into capital charges, fuel, maintenance, etc., and information as to water requirements.
>
> 4. Estimated amounts of primary and secondary hydropower available in 1970 and 1980, by regions, assuming capacity increments as in 3 above.
>
> 5. General comments by the Federal Power Commission on trends in the production of electric energy, on the power requirements of the Nation and means by which they can best be met, water requirements for hydropower and for cooling, and other matters which the Commission believes may be of value to the committee in its consideration of the Nation's water problems.

Six tables referred to in this report supply the information requested in items 1 to 5 as listed above. The text which follows will explain these tables, describe the general methods used in deriving the information, and indicate the limitations of the data. The text will deal with the five items in the order in which they appear in the letter from Senator Kerr.

1. *Electric energy demands and generating capacity requirements*

Tables 1 and 2 supply this information. Table 1 shows the peakloads of electric utility systems as well as loads supplied by nonutility generating plants. It should be pointed out that the electric power requirements of this country are supplied both by the generating facilities of electric utility systems and by establishments which are not utilities. The nonutility capacity is largely owned by industrial establishments, mainly manufacturing plants. Some capacity is owned by railroad and railway companies, and a small amount is operated by agricultural and commercial establishments and included in the nonutility category. At the end of 1958, the total capacity of the United States, excluding Alaska and Hawaii, was 161 million kilowatts. Of this capacity, 18 million kilowatts is classified as nonutility. Thus it is seen that the nonutility capacity is fairly substantial. The reason for so much capacity in nonutility plants is largely due to the fact that

TABLE 1.—*Peakloads by Federal Power Commission regions (1958 actual; 1980 estimated)*

[Thousand kilowatts]

Region	1958			1980		
	Utility	Non-utility	Total	Utility	Non-utility	Total
I	25,155	2,844	27,999	66,220	3,375	69,595
II	22,034	3,688	25,722	66,246	6,255	72,501
III	22,272	1,777	24,049	68,078	3,457	71,535
IV	14,334	1,357	15,691	45,918	2,370	48,288
V	13,553	2,791	16,344	43,311	5,430	48,741
VI	2,746	140	2,886	8,640	248	8,888
VII	9,166	550	9,716	30,567	795	31,362
VIII	11,007	394	11,401	37,300	570	37,870
United States	120,267	13,541	133,808	366,280	22,500	388,780

many industries require considerable amounts of steam and heat in their operations, making it economical to utilize some of the heat to generate electricity. This accounts to a large extent for the fact that most of the nonutility capacity—16 million kilowatts—is steam-electric. Less than a million kilowatts is hydroelectric and somewhat more than a million internal combustion.

The Federal Power Commission obtains comprehensive data on the operations of all electric utility systems, but it does not get comparable data on nonutility powerplant operations. Data which the Commission obtains from nonutility plants are primarily confined to installed capacity and electric energy generated. The Commission has almost no information on the cost of these plants, fuel consumed, or water requirements. The water requirements of nonutility hydroelectric and internal combustion plants are obviously inconsequential as related to the total water requirements of the Nation for generating electricity. Water requirements of the nonutility steam-electric plants would be substantial, but it would be difficult to separate them statistically into the amount needed for electric power generation and that needed for manufacturing or mining operations—and the latter requirements are by far the greater. Information on total water use by industry is available from the Bureau of the Census, but is not included herein. This report is largely confined to electric utility data, although figures on nonutility generation are shown in some of the tables in order to give an indication of its magnitude.

The nonutility data shown in table 1 are partially estimated from information gathered by a survey of industrial establishments conducted by the Federal Power Commission during World War II. Information was obtained not only on generating capacity but also on the maximum demands carried by such capacity. Since World War II the Commission has not obtained information on the actual loads supplied by nonutility generating plants. It has regularly collected data on installed capacity and generation of nonutility plants, but not on the actual peakloads carried by such plants. Therefore, the information gathered during World War II was used to derive ratios for use in estimating the nonutility peakloads shown in table 1. The figures may be quite approximate for this reason.

The Federal Power Commission, as a part of its regular work, prepares estimates of future electric loads in the various regions of the country and capacity needed to supply these loads. Its load forecasts are revised periodically and published. The latest forecasts of the Commission appear in a release of June 1959, and the data in table 1 are based on figures given in the release.

Table 2, which shows electric generating capacity at the end of 1958 by type of prime mover and estimates for 1980, also utilized the June 1959 release. However, it was necessary to make additional studies in order to derive a regional estimate of capacity by type—steam, hydro, and internal combustion. While the forecasting of future capacity requirements is obviously quite conjectural—particularly for a period of 20 years or more in the future—and while the figures in this report may thus prove to be high or low as time progresses, it is believed that they indicate the general magnitude of what may be expected and are useful and essential to power planning purposes.

The generating capacity requirements are, of course, related to anticipated load growth. Having forecasts of future electric loads, the problem of determining total necessary generating capacity involves making an allowance to cover reserve margins. Reserves are needed to allow for unforeseen outages of equipment, maintenance of equipment, unforeseen load fluctuations, and for other reasons. To break down the capacity by type of prime mover involves a number of considerations including possible retirements of older units due to wear or obsolescence. It was assumed in this study that the retirement of hydroelectric units in the period from now to 1980 would be insignificant, and that fuel-electric units would be retired at an age of from 30 to 40 years depending upon circumstances.

There is no exact way of forecasting capacity by type of prime mover. With respect to hydro capacity, the Federal Power Commission maintains a considerable amount of information concerning hydroelectric-power sites and makes investigations pertaining to hydroelectric capacity expected to be developed in future years. Projects to be built by the Federal Government depend upon congressional authorization, but non-Federal projects, both public and private, are subject to licensing by the Federal Power Commission. The Commission cooperates with Federal construction agencies on numerous power problems and is

TABLE 2.—*Year-end installed electric generating capacity by Federal Power Commission regions (1958 actual; 1980 estimated)*

[Thousand kilowatts]

Year	Ownership	Prime mover	Region								
			I	II	III	IV	V	VI	VII	VIII	United States
1958	Utility	Hydro	3,572	612	6,685	1,004	996	1,238	9,894	5,311	29,312
		Steam	24,342	27,258	18,882	14,752	14,038	2,196	977	8,639	111,084
		Internal combustion	269	235	181	705	857	333	63	141	2,784
		Total	28,183	28,105	25,748	16,461	15,891	3,767	10,934	14,091	143,180
	Nonutility	Hydro	346	131	70	121	3	9	48	2	730
		Steam	3,350	4,660	2,277	1,582	2,790	165	681	487	15,992
		Internal combustion	96	126	22	106	929	13	4	36	1,332
		Total	3,792	4,917	2,369	1,809	3,722	187	733	525	18,054
	Total	Hydro	3,918	743	6,755	1,125	999	1,247	9,942	5,313	30,042
		Steam	27,692	31,918	21,159	16,334	16,828	2,361	1,658	9,126	127,076
		Internal combustion	365	361	203	811	1,786	346	67	177	4,116
		Total	31,975	33,022	28,117	18,270	19,613	3,954	11,667	14,616	161,234
1980	Utility	Hydro	6,357	1,113	9,612	1,221	2,537	3,284	28,522	11,276	63,922
		Steam	69,196	74,720	68,378	50,385	45,470	6,102	6,530	31,519	352,300
		Internal combustion	600	350	300	1,200	1,800	550	100	100	5,000
		Total	76,153	76,183	78,290	52,806	49,807	9,936	35,152	42,895	421,222
	Nonutility	Hydro	350	130	70	100	0	0	50	0	700
		Steam	4,000	8,000	4,500	2,900	5,000	300	1,000	700	26,400
		Internal combustion	150	210	40	160	2,240	30	10	60	2,900
		Total	4,500	8,340	4,610	3,160	7,240	330	1,060	760	30,000
	Total	Hydro	6,707	1,243	9,682	1,321	2,537	3,284	28,572	11,276	64,622
		Steam	73,196	82,720	72,878	53,285	50,470	6,402	7,530	32,219	378,700
		Internal combustion	750	560	340	1,360	4,040	580	110	160	7,900
		Total	80,653	84,523	82,900	55,966	57,047	10,266	36,212	43,655	451,222

actively involved in licensed projects both under construction and being considered for future construction. Also, a number of projects are in the exploratory stage and require a preliminary permit from the Federal Power Commission allowing the parties involved to formulate plans and estimates for certain projects to be proposed for construction at some future date, with the assurance that a license will not be issued to any other party while the preliminary permit is active. All of the potential water-power sites in the country have been studied by the Federal Power Commission and data have been developed on the available head, the capacity likely to be installed at these sites, and the amount of energy that would be generated in an average water year. Therefore, it can be assumed that the figures on future hydroelectric capacity shown in table 2 are fairly reliable.

As for internal combustion capacity, it is seen from table 2 that it represents a small part of the total. Data on future internal combustion additions have been estimated by the Commission staff from information on past trends, present installations, and engineering aspects with regard to the usefulness of internal combustion plants in meeting future loads. Most of the internal combustion plants are small, and they are being installed today mainly by municipal electric systems which supply their own requirements and are not interconnected with larger electric utility systems. Internal combustion plants are also utilized to some extent by larger utilities for peaking purposes. The total amount of internal combustion capacity to be installed in the future probably will be relatively small as compared with the total capacity requirements.

Having made estimates of the amount of hydroelectric and internal combustion capacity needed in the future, the amount of steam-electric capacity required—by far the largest part of the total—is derived by deducting hydroelectric and internal combustion capacity from total needs.

2. *Per capita electric requirements and requirements by category of use*

Table 3 shows electric power requirements in the United States broken down into the categories of use utilized by the Federal Power Commission in its load forecasting work. Also shown in table 3 are forecasts of future population and energy consumption per capita. The latest power requirements forecasts of the Federal Power Commission extend to 1980. For the purposes of this study the forecasts have been extended to the year 2000. The forecasts to the year 1980 involve detailed analyses of the past uses of electricity and prospects for future growth. The figures for the year 2000 represent graphical extension of the forecasts to 1980, assuming that the rate of growth in the period 1975–80 will continue to the year 2000. The population forecast for 1980 is based on the Bureau of the Census release, "Current Population Reports," series 25, No. 187. This document gives four series of projections to the year 1980.

TABLE 3.—*Electric energy requirements of the United States (1958 preliminary actual; 1980 and 2000 estimated)*

	1958	1980	2000
Electric energy requirements(million kilowatt-hours):			
Utility requirements:			
Farm, excluding irrigation and drainage pumping	22,369	45,732	76,581
Irrigation and drainage pumping	8,000	18,816	28,969
Nonfarm, residential	143,338	506,431	1,191,277
Commercial	101,056	306,258	670,265
Industrial	283,280	870,433	1,750,820
Street and highway lighting	6,047	15,045	29,456
Electrified transportation	4,081	5,025	5,394
Other deliveries to ultimate consumers	18,680	42,667	78,539
Losses and unaccounted for	64,049	202,187	428,354
Total	650,900	2,012,594	4,259,655
Nonutility generation less deliveries to electric utilities	77,187	148,000	203,000
Total energy requirements	728,087	2,160,594	4,462,655
Population, including Armed Forces overseas, July 1 (thousands)	174,064	272,557	425,189
Energy requirements per capita (kilowatt-hours)	4,183	7,927	10,496

The figure shown in table 3 for the year 1980 represents the highest series (series 1) given in the Census report. Beyond 1980, the indicated annual rate of growth between 1975 and 1980 as shown in the Census report is assumed to continue over the period 1980–2000.

3. *Means of adding capacity, costs, and water requirements*

Table 2, already discussed, shows the estimated breakdown of capacity additions by type of prime mover. Table 4 shows estimated costs for the year 1980. The figures in the latter table are of necessity based on a number of assumptions. The Federal Power Commission's data on present and past costs for individual electric utility systems are quite extensive. Nevertheless, although much of this information has been summarized on a national basis, regional summaries are in general not available. Because of the large number of utility systems involved, it would be a time-consuming task to summarize the available cost data on a regional basis. Therefore, approximate methods were used in order to derive the data in table 4.

TABLE 4.—*Electric utility costs in 1980*[1] *by Federal Power Commission regions*

[Million dollars]

Region	Fixed costs	Fuel costs	Other electric operating costs	Total electric costs
I	4,643	1,410	1,598	7,651
II	3,747	1,002	1,031	5,780
III	2,421	963	1,131	4,515
IV	3,174	774	1,406	5,354
V	2,479	347	979	3,805
VI	620	115	316	1,051
VII	926	139	488	1,553
VIII	2,040	603	941	3,584
United States	20,050	5,353	7,890	33,293

[1] Excludes capital costs of new construction in 1980 which may amount to about $6,000,000,000.

As to future costs, there obviously are a number of imponderable factors involved, and there is no accurate method of forecasting price trends. Also, as regards fixed costs, which are a large part of the total costs, these depend upon type of ownership—whether the electric facilities are owned by private companies, the Federal Government, or by non-Federal public bodies—and political considerations thus become a factor in future costs.

While capital construction costs are considerably higher today than prior to World War II, costs have not changed materially in the last few years, and resort to larger generating units and other practices will undoubtedly tend to prevent unit costs from rising in the future. Fuel prices for each of the conventional fuels—coal, oil, and gas—are higher today than they were 15 years ago; but except for gas, prices have changed little in the past 10 years. The increase in gas prices has not significantly affected the total overall fuel cost per B.t.u.—the combined cost of the three fuels. This is because gas is still the cheapest fuel nationally and its portion of total fuel use in electric utility plants has risen substantially. Fuel costs per kilowatt-hour have actually been declining over the years because of the consistent improvement in heat rates which has lowered the amount of fuel required to generate a kilowatt-hour of electric energy. There is, of course, a limit to the efficiencies that can be reached in producing a kilowatt-hour of energy, so that overall fuel costs cannot continue to decline indefinitely.

Unit operating costs other than fuel, including other production costs, transmission and distribution costs, administrative, sales promotional, and other expenses, have declined in spite of price inflation, not only because of operating economies but also because of the increasing use of electricity which has raised the kilowatt-hour consumption per customer and has thus naturally lowered unit costs.

It would be highly conjectural to project price trends into the future since a variety of unpredictable factors are involved, including questions of a political nature. Therefore, for the purposes of this study, fuel costs and other operating costs are assumed to continue at present levels and future capital costs have been assumed at about those experienced in the past few years.

The figures shown in table 4 are based on estimated electric plant required in the year 1980, which will consist of present plant still in use by 1980 plus new facilities needed between now and 1980, including not only generating plants but transmission and distribution lines and other necessary construction. Also, allowance was made for electric plant being built in 1980 but not yet in service at that date, commonly designated as "construction work in progress." Fixed costs given in the table include cost of money, depreciation, amortization, taxes, and payments in lieu of taxes. Fuel costs in 1980 were determined by utilizing present heat rates and present fuel prices. It is recognized that heat rates are expected to decline, but fuel prices are likely to rise. These factors may possibly be compensating. Therefore, present levels are considered to be adequate for this estimate. Other electric operating costs are based on 1957 experience for the United States as a whole adjusted to account for variations among regions. There is a considerable amount of detail in the work papers to support the figures shown in table 4, but it is felt that no useful purpose can be served by going into further detail in this report. Also, it is felt that a further breakdown of the costs into categories not shown in the table would not be warranted. All the cost figures must be considered as quite approximate.

Table 5 shows estimates of the 1980 water requirements of steam-electric plants and hydroelectric plants on a regional basis. This table is included in order to give a rough indication of the general magnitude of water requirements in 1980, and too much reliance should not be placed on its accuracy for a number of reasons.

The major use of water in steam-electric plants is in the condenser where a vacuum is created resulting in a reduction in the heat required to generate a kilowatt-hour of electric energy. This does not represent a consumptive use of water. Consumptive use of water in steam-electric plants is very small as explained later in the general discussion under item 5. The water requirements of the condenser depend upon the temperature-pressure, and quantity of steam required to generate a kilowatt-hour of electricity in the particular plant; the temperature of the condenser cooling water; and the amount of vacuum.

TABLE 5.—*Water requirements of electric utilities in 1980 by Federal Power Commission regions*

Region	Steam-electric generation (billion kilowatt-hours)	Gallons per kilowatt-hours	Steam-electric water requirements (million acre-feet)	Hydroelectric generation (billion kilowatt-hours)	Average head [1] (feet)	Hydroelectric water requirements (million acre-feet)
I	327	58	58	32	188	200
II	370	54	61	4	62	76
III	343	46	48	33	123	316
IV	240	62	46	6	52	136
V	200	53	32	7	111	75
VI	31	58	6	14	221	75
VII	48	53	8	134	200	792
VIII	163	62	31	49	720	80
United States	1,722	55	290	279	275	1,750

[1] Weighted by kilowatt-hours generated at each site.

The Federal Power Commission conducted a survey of water requirements of electric utility systems in 1954 and the material was assembled on a State basis. Utilizing this information and making allowance for improved efficiency of generation over the next 22 years, and taking into consideration other technical factors, an estimate was made of the quantity of water that would be needed in each region of the country for each kilowatt-hour of electric energy produced. Table 5 shows the information and also gives data on total water use at steam-electric plants as computed from the unit figures.

Water requirements of hydroelectric plants are substantially greater than for steam-electric plants, but here again the use is not of a consumptive nature. The composition of the water is not changed, there is no pollution involved, and there is little effect, if any, on the temperature. In the latter respect steam-electric plants are quite different since the temperature of the water used in the condenser is raised significantly.

Table 5 gives estimates by regions of the total amount of water that will be passed through hydroelectric plants in 1980 assuming an average water year. The figures should be considered as highly approximate since time did not permit a detailed determination of the average head on a regional basis. Also an approximate formula was used to compute the water requirements from estimated figures on head and average kilowatt-hours of generation. Additional study will have to be made in order to determine how such information can be best utilized so as to be meaningful in the investigation of the country's water problems. Hydroelectric plants use the same water that has been released from plants upstream, and the combined total of waterflows at a series of plants gives an unrealistically large figure which is not related to the flow of the river at any one point. This is a problem which will be explored further with the view to developing supplemental data of value, possibly with respect to water requirements of the largest plants on a particular river or the water requirements of plants which use the largest amounts of water, even though they are not necessarily the biggest plants in terms of electric power production.

4. Primary and secondary hydropower

This information cannot be derived in exactly the form desired, but table 6 may be of use. The electric utility systems, in their reports to the Federal Power Commission, supply complete hourly load data for a number of days in the year. Also, information is obtained on monthly energy requirements and monthly peak demands. From such data load duration curves can be constructed, and this was done on a regional basis in connection with this report. However, such information is useful only as a rough indication of how much energy there is in the base of the load and how much there is in the peak. Just where the future generation by type of prime mover would be utilized on the load duration curve is something that cannot be predicted from the information available. Secondary power is not confined to hydroelectric generation alone, for even in areas which are predominantly steam-electric in character secondary power is sold at certain periods of the year. As a matter of fact it is difficult to distinguish between the various categories of power that are not firm. Categories such as secondary, interruptible, surplus, dump, nonfirm, and offpeak are more or less similar, differing mainly from the standpoint of hours of availability, and each utility may have a slightly different definition for these categories. In most areas of the country, hydropower and fuel-electric power complement each other and it is not possible to determine how much of the secondary power is hydroelectric and how much is fuel-electric. In an area such as the Pacific Northwest, where large amounts of interruptible and secondary power are sold, there is no question that such power comes from hydroelectric plants because they account for nearly all of the power that is produced in the area at the present time. However, by 1980 a large amount of fuel-electric capacity will be needed in the Northwest and one of the purposes of the fuel plants will be to firm up the area's hydroelectric resources which will consequently reduce the amount of secondary energy available. But it would be very difficult to predict specific quantities.

In many areas of the country, systems which are predominantly steam-electric in character have interruptible loads which are permitted to utilize surplus power at reduced prices. For example, the Tennessee Valley Authority, with nearly twice as much steam-electric capacity as hydroelectric, has a number of large interruptible loads which can be reduced if capacity—not only hydroelectric but steam-electric as well—is insufficient to meet peakloads. Also, throughout the country utility systems buy and sell secondary power either from hydroelectric or from steam-electric resources.

TABLE 6.—*Electric utility 1980 energy requirements by Federal Power Commission regions*

[Billion kilowatt-hours]

Region	Total generation	Base energy	Peak energy	Fuel generation	Hydro generation
I	360	188	172	328	32
II	375	210	165	371	4
III	377	175	202	344	33
IV	248	117	131	242	6
V	211	119	92	204	7
VI	46	25	21	32	14
VII	182	118	64	48	134
VIII	212	111	101	163	49
United States	2,011	1,063	948	1,732	279

Table 6 shows an estimated breakdown of generation in 1980 between hydro and fuel generation on a regional basis. The hydro generation is based on average water conditions. In every region except VII, which is comprised largely of the Pacific Northwest, the peaking energy requirements are considerably larger than the amount of energy that will be available from hydroelectric plants. It cannot be said categorically, however, that hydroplants in all regions except VII will operate in the peak of a load, because numerous hydroplants in each region will have sufficient water to operate fairly continuously in the base of the load. In region VII some of the hydro capacity will provide the requirements in the base of the load and a part of it will be required for peaking. The same reasoning holds for thermoelectric plants.

5. *General comments on power production trends and water requirements*

It has previously been stated that use of water at both hydroelectric and steam-electric plants is, for the most part, not of a consumptive nature. Nevertheless, it might be of interest to point out certain problems in connection with such water use.

The power that can be generated at a hydroelectric project depends primarily on the amount of water available and the hydraulic head. The greater the amount of flow and the greater the head, the more power that can be generated. A river fully developed from its headwaters to its mouth would utilize the entire fall in the river. But in practice this degree of utilization is not possible, not only for physical reasons but for economic reasons as well. As a general rule, sites for building hydroelectric projects are selected so as to give the best use of the water available at the location at the lowest possible cost. Most hydro projects in the United States are single-purpose developments but many major river development projects involve other purposes such as navigation, flood control, irrigation, and other uses. The problems encountered in selecting multiple-purpose project sites and designing the projects are much more complex than for single-purpose power projects, and it is sometimes difficult to reconcile the various uses to the best advantage of overall needs Provision for flood control requires that a reservoir contain more storage space and that the powerplant operate at lower head than would be desirable for power generation alone. Releases of water for navigation do not coincide with releases normally necessary for power generation. Water required for irrigation is usually not available for power generation, and at some multiple-purpose projects power is actually consumed in the process of pumping the water into irrigation canals, thus taking away from the power that would be available if the project were a single-purpose power development.

In connection with license applications before the Federal Power Commission, there are frequently important problems that have to be considered with respect to release of water for nonpower uses consistent with needs for power purposes. For example, certain licenses provide for storage space downstream from the project so that water may be available for irrigation when water is being stored by the licensee in headwater reservoirs. Licenses may include provisions for minimum releases in order to maintain water levels downstream sufficient for water supply, fish preservation, and other needs, and the required releases can vary during the year. Some licenses contain stipulations regarding minimum releases because industrial wastes and municipal sewage are being dumped into the river downstream from the project. Licenses may have provisions to limit the rate at which water is to be discharged through the turbines, which prevents the plant from being brought up to load as rapidly as desired on certain occasions. Other licenses have regulations governing the release of water in order to assure a certain amount of storage space for flood control and in order to provide a minimum flow for navigation. Licensees are sometimes required to construct regulating dams downstream in order to reregulate power releases in the interest of fish preservation, and the protection of life, health, and property. In summary, it can be stated as a general rule that projects are operated so that power production does not seriously interfere with use of the water for other purposes. Water needs for municipal water supply, navigation, irrigation, flood control, fish preservation, and other purposes usually have priority over requirements for the generation of power.

It is commonly assumed that use of water at hydroplants is not a consumptive use. One might argue however, that this is not strictly true inasmuch as most large hydroelectric developments have considerable storage capacity as opposed to run-of-river projects which generally have very small ponds. Wherever storage is involved, there are water losses due to evaporation. This is a problem which the Select Committee on National Water Resources is no doubt having investigated by other agencies of the Government. The problem of evaporation is a difficult one since the water evaporated is not in fact lost but returns to land or ocean at a later part of the hydrologic cycle;

but the water may return in a location different from the project. Silting is another problem which is probably being handled by another Government agency.

With respect to water use at steam-electric plants, the figures shown in table 5 apply to total water requirements. A small amount of the total is represented by boiler feed water and some of this is lost, but the amount is insignificant. Some utility companies make use of storage ponds from which water is taken for condensing purposes and returned for reuse after it has been permitted to cool. There is, of course, evaporation from such ponds. Other utility systems do not have an adequate supply of condensing water and must utilize cooling towers. This also involves evaporation loss. However, total water loss at steam-electric stations is comparatively unimportant, but total water use is very significant.

The amount of water required by steam-electric generating stations is a very important factor in determining the location of plants. In any closed cycle steamplant—and all utility plants are of this type—condenser water must be used to obtain satisfactory efficiencies. It would not be economical or technically feasible to provide enough turbine blading to extract so much of the heat from the steam that it would be discharged to the boiler feed lines as condensed water without the use of a condenser. If the steam were not condensed or used for other purposes such as process heat for nearby factories, it would have to be wasted by discharge to the atmosphere. The more water that is used for condensing purposes, the greater is the efficiency; but economics determines the amount. The cost of providing additional condensing water must be balanced against the savings resulting from the increased efficiencies which can be obtained.

An ample supply of condenser water is an asset to efficient operation, but thermal plants are often built where water supplies are very limited. In general it is not expected that there will be a physical lack of water in the country for condensing purposes because water requirements can be reduced, although at the cost of reduced efficiency, and also cooling towers can be utilized. Use of cooling towers increases the total cost but results in reduced fuel costs. The ideal situation would be to have an unlimited supply of cool water which would flow by natural gravity through the condenser. With conditions less favorable than this, plant design and operation can be altered to fit the available water supply.

It may be well to touch upon the point that the estimates of steam-electric capacity needed in the future, as given in this report, are not broken down by type of fuel. The three conventional fuels being used at the present time are coal, oil, and gas. Coal accounts for about 65 to 70 percent of the present generation in electric utility plants. Gas accounts for close to a quarter of the total, and oil less than 10 percent. Nuclear power is now coming into the picture, and the 1958 figures on installed generating capacity include about 110,000 kilowatts in nuclear plants. Both technical considerations and economics will control the rate of development of nuclear power. At this stage of development, it is hazardous to attempt to estimate how fast nuclear-power production will expand. But from the standpoint of water needs, the requirements of nuclear plants should not be greatly different from those of steam-electric plants if the same thermal efficiencies are assumed. Nuclear plants are not yet as efficient, however, as conventional plants. In this connection, it should be pointed out that one of the factors which will reduce the future requirements of water at steam-electric plants is the increasing efficiency of these plants. The most modern high-pressure, high-temperature steam-electric plants require considerably less water per kilowatt-hour than the older plants. There is a limit, however, to how much improvement can be made in thermal plant efficiencies.

One other matter should be noted in this report and that is the fact that the figures in the tables do not include Alaska or Hawaii. At the end of 1958, Alaska had 350,000 kilowatts of generating capacity of which 68,000 kilowatts were hydroelectric. Hawaii had an installed capacity of 400,000 kilowatts of which only 17,000 kilowatts were hydroelectric. Alaska has a total undeveloped hydroelectric power potential of about 19 million kilowatts. Hawaii's undeveloped hydroelectric resources are small and are estimated at 300,000 kilowatts. The Federal Power Commission does not have adequate information on the water requirements of generating plants in Alaska and Hawaii to permit an estimate at this time of the future water requirements of these States.

REPORT OF THE EDISON ELECTRIC INSTITUTE ON THE FUTURE OF THE ELECTRIC POWER INDUSTRY IN RELATION TO WATER RESOURCES

JUNE 23, 1959.

Mr. EDWIN VENNARD,
Managing Director, Edison Electric Institute,
New York, N.Y.

DEAR MR. VENNARD: Under the provisions of Senate Resolution 48, adopted April 20, 1959, the Select Committee on National Water Resources has been established. The committee is taking steps now to assemble and analyze as expeditiously as possible information on the Nation's many water problems.

One of the major uses of water is, of course, in the generation of electric power, both in hydroelectric plants and for cooling purposes in steam electric generating plants. The committee is seeking information on anticipated water requirements for these purposes between now and 1980, and would appreciate it very much if the Edison Electric Institute could furnish us with its views on the future development of the power industry in the United States along the following general lines:

1. Electric energy demands and capacity requirements by region, at present and projected to 1970 and 1980, with a breakdown to show the extent to which demands are met and anticipated to be met by hydro, thermal, or other sources, including nuclear energy.

2. Estimates of per capita electric energy demands for the United States for the present and in 1970, 1980, and 2000, in the following categories:

   (*a*) Household and farm.
   (*b*) Industrial and commercial.
   (*c*) All other.

3. Recommended means of adding capacity, 1970 and 1980, by region, with costs of production for each broken down to the extent possible into capital charges, fuel, maintenance, etc., and with information as to water requirements.

4. Estimated amounts of primary and secondary hydropower that can be developed in 1970 and 1980, by regions, assuming capacity increments as in 3 above.

5. General comments by the Edison Electric Institute on trends in the production of electric energy, on the power requirements of the Nation, and means by which they can best be met, on water requirements for hydropower and for cooling, and on other matters which the Edison Electric Institute believes may be of value to the committee in its consideration of the Nation's water problems.

Similar information is being requested of the Federal Power Commission and for this reason we would like your studies to conform to the regional breakdown and power use categories used by the Commission. We are also making a similar request to the American Public Power Association. We would like this information to be made available in a summary report of not more than 10,000 words with whatever tables, charts, and appendixes as may be considered necessary. It would be most helpful if this report could be furnished the committee by October 1, 1959.

The committee has set up a small staff of which Mr. Theodore Schad is director. Should you have any questions with respect to the information desired, you may wish to communicate directly with him. A copy of Senate Resolution 48 and a general outline of material being gathered for the committee is enclosed to give you an idea of the general framework within which the committee is working.

We appreciate your cooperation in this matter.

Sincerely yours,

ROB'T S. KERR, *Chairman.*

EDISON ELECTRIC INSTITUTE,
New York, January 14, 1960.

Hon. ROBERT S. KERR,
U.S. Senate, Washington, D.C.

DEAR SENATOR KERR: This letter, together with the attached detailed report, is in reply to your request dated June 23, 1959, relative to the Nation's water resources.

Your request is in five parts. For convenience, we are stating each one in turn, giving our general views thereon, and pointing out that further information on the subjects involved will be found in the detailed report.

Request No. 1.—Electric energy demands and capacity requirements by region, at present and projected to 1970 and 1980, with a breakdown to show the extent to which demands are met and anticipated to be met by hydro, thermal, or other sources, including nuclear energy.

Response.—The estimated energy demands and capacity requirements by Federal Power Commission regions (as shown on the enclosed map) for the electric utility industry of the United States is given in the following table. The industry includes investor-owned companies, Federal and non-Federal governmental agencies and cooperatives. It does not include industrial, mine, railway electric powerplants, and isolated plants such as those in institutions, hotels, apartment houses, and office buildings.

Peakload and energy requirements

FPC region	1959		1970		1980	
	Peakload (megawatts)	Energy requirements (million kilowatt-hours)	Peakload (megawatts)	Energy requirements (million kilowatt-hours)	Peakload (megawatts)	Energy requirements (million kilowatt-hours)
I	27,312	138,846	49,815	268,468	82,851	458,776
II	23,839	140,644	45,507	267,200	84,093	493,600
III	23,909	138,220	55,105	310,093	110,209	612,062
IV	[1] 14,744	80,649	[1] 29,147	151,757	[1] 53,125	276,768
V	[1] 14,185	69,967	[1] 40,315	197,023	[1] 88,580	440,406
VI	2,613	13,102	7,020	35,583	14,791	72,425
VII	9,867	57,021	19,500	108,624	35,700	193,158
VIII	[1] 12,159	68,465	[1] 25,383	142,318	[1] 44,445	247,665
Total	[2] 129,000	706,914	[2] 265,000	1,481,066	[2] 501,000	2,794,860

[1] Designates a summer peak.

[2] The total peakload is not the sum of the individual regional peaks because the regional peaks are at the time of their maximum regardless of when they occur. The total peakload is the estimated annual maximum for the country as a whole.

The breakdown by hydro, thermal and other sources, including nuclear energy, because of its technical nature and the limitations of the information available to the institute which necessitate considerable explanation, will be found in the detailed report attached.

Request No. 2.—Estimates of per capita electric energy demands for the United States for the present and in 1970, 1980, and 2000, in the following categories:

(*a*) Household and farm.
(*b*) Industrial and commercial.
(*c*) All other.

Response.—The following table gives the institute's estimates for 1970 and 1980. These estimates are based on an extension of the population estimates of the Bureau of the Census, and a projection of postwar trends of electric requirements as related to gross national product.

	1959	1970	1980
Estimated population (millions)	176	208	245
	Kilowatt-hour per capita		
Kilowatt-hour sales:			
Domestic (residential and rural)	1,044	2,161	3,749
Industrial and commercial	2,354	3,939	6,071
Other	147	192	204
Total sales	3,545	6,292	10,024
Losses	465	821	1,366
Requirements of the utility industry	4,010	7,113	11,390
Self-generation by industries, etc	471	442	407
Requirements of the United States	4,481	7,555	11,797

To project kilowatt-hour sales per capita by classes of customers to the year 2000, 40 years hence, involves a great deal of speculation. Studies of the institute indicate that total output will probably be between 6 and 10 trillion kilowatt-hours, depending on the rate of growth of the national economy and the rate at which new energy uses are introduced, especially electric space heating. On the basis of a population of 340 million, total per capita output in the year 2000 should be on the order of 17,600 kilowatt-hours to 29,400 kilowatt-hours. Sales should be in about the same proportion among customer classifications as in 1980, with a possible increase in the proportion of domestic sales.

Request No. 3.—Recommended means of adding capacity, 1970 and 1980, by region, with costs of production for each broken down to the extent possible into capital charges, fuel, maintenance, etc., and with information as to water requirements.

Response.—The study shows the following results for the equipment owned by the investor-owned utility companies.

Capability in service at time of regional peak

[In megawatts]

Year	Thermal		Hydro	Other sources [1]	Total
	Conventional	Nuclear			
1959	111,757	65	12,486	3,019	127,327
1970	225,417	7,719	20,003	9,784	262,923
1980	416,722	38,900	24,926	11,779	492,327

[1] Other sources include firm capability available from other than investor-owned systems and nonutility facilities, plus adjustments arising from interregional transfers.

The conditions which prevail in the United States in respect to topography, climate, rainfall, water supply, fuel supply, transportation and costs are so variable that the results cannot be reduced to summary form. The various matters involved are discussed in considerable detail for each region in the attached report.

The water requirements of the above thermal capacity are affected by the cooling water methods used. These are:

"Once through," where water is taken from a stream, lake or the ocean, passed through the condenser, and returned to the source.

Cooling ponds, where the water is taken from the pond, and after passing through the condenser is returned to the pond.

Cooling towers, where the process is similar to the cooling pond, except that the water is cooled in a tower after passing through the condenser.

The volume of water involved is anticipated to be as follows:

Total water circulated through condensers

[Billion gallons annually]

Year	Rivers	Lakes	Brackish and sea water	Cooling towers	Artificial reservoirs or ponds	Total
1959	12,428	3,254	7,820	2,755	556	26,813
1970	23,842	8,168	16,155	6,935	2,185	57,285
1980	42,754	15,260	28,015	15,487	4,892	106,409
	Consumptive use of water					
1959	(1)	(1)	(1)	42	10	----
1970	(1)	(1)	(1)	111	39	----
1980	(1)	(1)	(1)	218	89	----

[1] Less than 1 percent.

Accurate information as to the total volume of water passing through the turbines of the hydroplants is not available at this time. Except for evaporation from reservoirs in arid regions and during droughts in other areas, there is no net loss of water in hydro stations.

Request No. 4.—Estimated amounts of primary and secondary hydropower that can be developed in 1970 and 1980, by regions, assuming capacity increments as in 3 above.

Response.—The electric companies do not contemplate the construction of hydro stations solely for the generation of secondary energy.

The companies do plan to make the most effective use possible of all types of energy that is now or will be available from their hydro resources.

Request No. 5.—General comments by the Edison Electric Institute on trends in the production of electric energy, on the power requirements of the Nation, and means by which they can best be met, on water requirements for hydropower and for cooling, and on other matters which the Edison Electric Institute believes may be of value to the committee in its consideration of the Nation's water problems.

Response.—The information given in the appended report indicates that the generating capability required to meet the future power needs of the Nation will be primarily thermal.

The art of designing, building, and operating steam electric stations is still advancing, with no end in sight. The technical progress in this field in raising pressures, temperatures, speed, unit sizes, and in developing advanced methods of cooling, supervision and control in the past 25 years alone has improved thermal efficiency by over 40 percent. In terms of 1959 generation this saved over 150 million tons of coal equivalent over what would have been required at the thermal efficiency of 25 years ago.

These and other very substantial advances have made available economies of a scale sufficient to maintain construction costs per unit of capacity at a relatively constant level despite significant increases in construction and other costs.

Advances in transmission, distribution, and utilization have accompanied the technological improvements in power production, to the end that this Nation today has the most abundant supply of electric power of any country in the world, at the same time the average price per kilowatt-hour has been reduced in the face of a rising price level for the economy as a whole.

An examination of research now being carried on by the utility industry in such fields as magnetohydrodynamic generation, thermionic and thermoelectric generation, the steam gas turbine cycle, nuclear generation, transmission at 700 kilovolts and above, and in every phase of electric power supply, promise a continuation of the industry's outstanding record of performance.

A word about nuclear generation is in order. The projection of nuclear generation in this report is based on what is presently known about nuclear technology. The industry is exerting great effort, however, toward achieving a technological breakthrough which would make nuclear energy economically competitive throughout the country. As these efforts meet with success, the industry's current research and training activities will insure the realization of the full advantage of nuclear power and place the industry in a position to add nuclear capacity more rapidly than the estimates shown in this report.

There is a great misconception held by many people that hydroelectric power is always more economical than steam-electric power. Such is not the case. Hydroplants generally require a much higher investment per kilowatt than do conventional steam-electric stations, and generally require much more extensive transmission facilities. In the future hydro development will be planned to meet special characteristics of the various area loads. An increased use of pumped storage hydros is expected.

Adequate water is essential for thermal powerplant operation. The industry, however, is not a significant consumer of water. Less than 1 percent of the water circulated through thermal electric stations is lost through evaporation. Except through reservoir operation in arid regions and in other areas in periods of extreme drought, there is no net loss of water in hydro stations.

Request No. 5 also solicits comments on how the future power needs of the Nation can best be met. The investor-owned utilities have, since the inception of the industry, been largely responsible for the rapid progress that has resulted in the abundant supply of electricity that is available throughout the country.

The United States is far ahead of the rest of the world in the extent and high quality of its electric service. The institute believes that the best way to insure an adequate future supply of electricity and a continuation of high quality service, at the lowest practical cost, is to continue along proven lines.

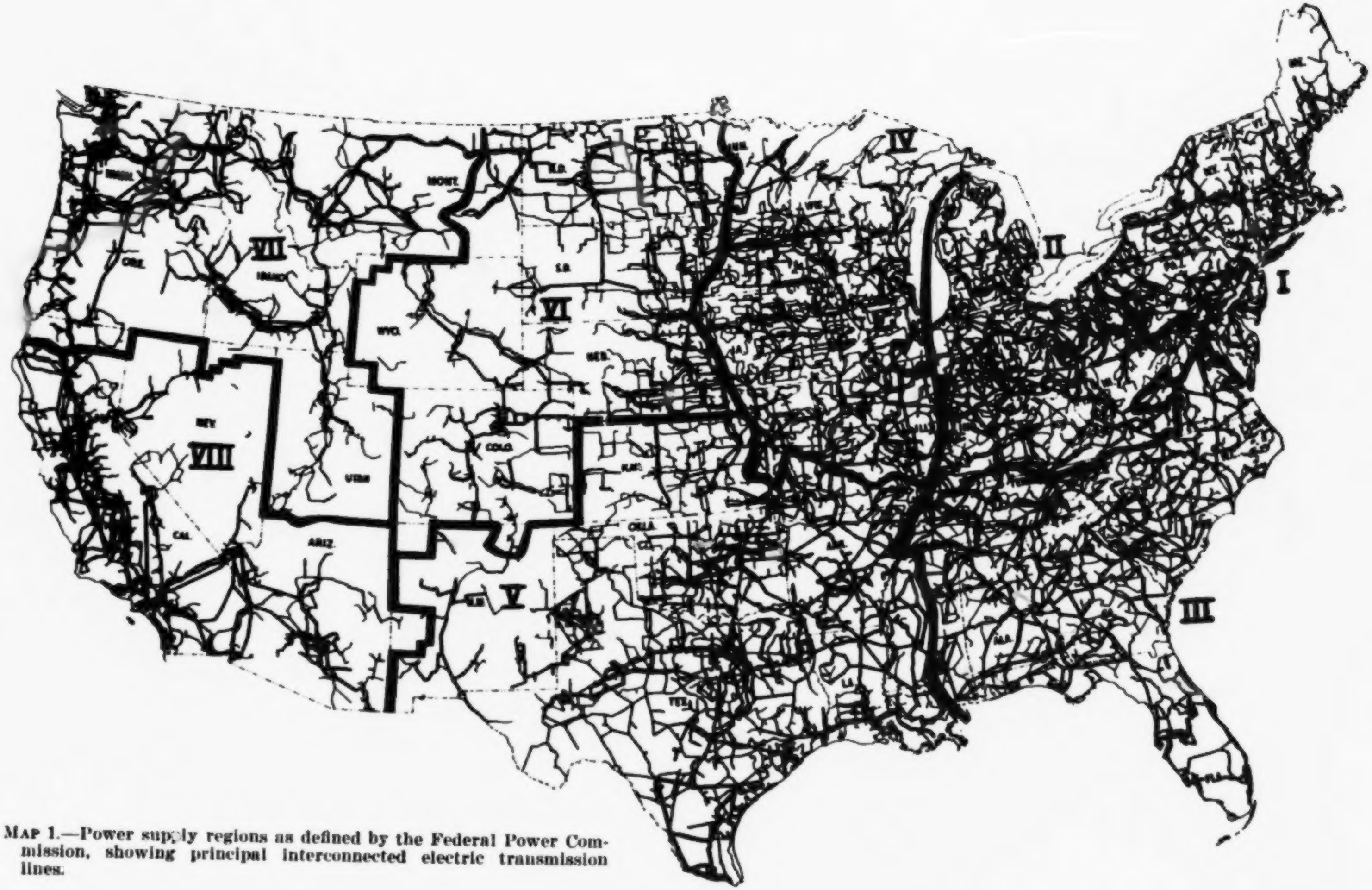
An important consideration in respect to the future is that the investor-owned utilities stand ready, able, and willing to meet in full the future power needs of this country in a manner calculated to serve the best interest of the public.

In respect to multiple-purpose projects the companies are ready, willing, and able to construct the power facilities under Federal license, and pay a substantial and fair fee for the use of the water for power.

The Edison Electric Institute is glad to be of assistance to the committee in this important matter.

Yours very truly,

ALLEN S. KING, *President.*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MAP 1.—Power supply regions as defined by the Federal Power Commission, showing principal interconnected electric transmission lines.

SUBSTANTIATING REPORT

Purpose of Report

This detailed section of the report has been prepared and is being submitted by the Edison Electric Institute in compliance with a request of the Select Committee on National Water Resources. The select committee was established by Senate Resolution 48 to make exhaustive studies of the extent to which water resources activities in the United States are related to the national interest, and the extent and character of water resource activities, both governmental and nongovernmental, that can be expected to be required to provide the quantity and quality of water for use by the population, agriculture, and industry between the present time and 1980.

Scope of Report

Because of the use of water in the generation of electric power, both in hydroelectric plants and for cooling purposes in steam electric generating plants, the select committee requested from the investor-owned utility industry information on anticipated water requirements for these purposes between now and 1980. This request was made in the form of a letter dated June 23, 1959, from Senator Robert Kerr, chairman of the select committee, to Mr. Edwin Vennard, managing director, Edison Electric Institute. In his letter Senator Kerr asked for the institute's views on the future development of the power industry in the United States along the following lines:

1. Electric energy demands and capacity requirements by region, at present and projected to 1970 and 1980, with a breakdown to show the extent to which demands are met and anticipated to be met by hydro, thermal or other sources, including nuclear energy.
2. Estimates of per capita electric energy demands for the United States for the present and in 1970, 1980, and 2000, in the following categories:
    - (*a*) Household and farm.
    - (*b*) Industrial and commercial.
    - (*c*) All other.
3. Recommended means of adding capacity, 1970, and 1980 by region, with costs of production for each broken down to the extent possible into capital charges, fuel, maintenance, etc, and with information as to water requirements.
4. Estimated amounts of primary and secondary hydropower that can be developed in 1950 and 1980, by regions, assuming capacity increments as in 3 above.
5. General comments by the Edison Electric Institute on trends in the production of electric energy, on the power requirements of the Nation, and means by which they can best be met, on water requirements, for hydropower and for cooling, and on other matters which the Edison Electric Institute believes may be of value to the committee in its consideration of the Nation's water problems.

A task force comprising electric utility company representatives from each Federal Power Commission region supplied most of the information contained in this report. No attempt was made in this report to round off the figures developed by the members of this task force. The institute does not have complete information on how power suppliers other than the investor-owned utility companies will expand their capacity requirements in the future years of 1970 and 1980. Consequently, the material in the report discussing recommended means of serving future loads has been confined to investor-owned systems. In estimating future hydro capability additions to investor-owned systems, the analysis made did not indicate any valid distinction between primary and secondary hydropower or any reliable basis on which to accurately determine production costs. A more detailed discussion of these points is contained in section IV of the report.

Answers to the information requested, subject to the qualifications cited above, are given below under the following headings:

- I. Peakload, capability, and energy requirement forecasts.
- II. Production costs of representative conventional thermal plants.
- III. Nuclear power.
- IV. Hydro development.
- V. Water requirements for thermal plants.

I. PEAKLOAD, CAPABILITY, AND ENERGY REQUIREMENT FORECASTS

Forecasts for total United States

Forecasts of peakload, capabilities, and energy requirements of the total electric utility industry were made by the institute for the years 1959, 1970, and 1980.

In order to supply this information by FPC regions, as requested by the select committee, the task force members made estimates of the peakloads and energy requirements in their respective regions. To estimate per capita electric energy use for the entire United States by sales classifications forecasts were made of kilowatt-hour sales in the respective categories. These forecasts were then

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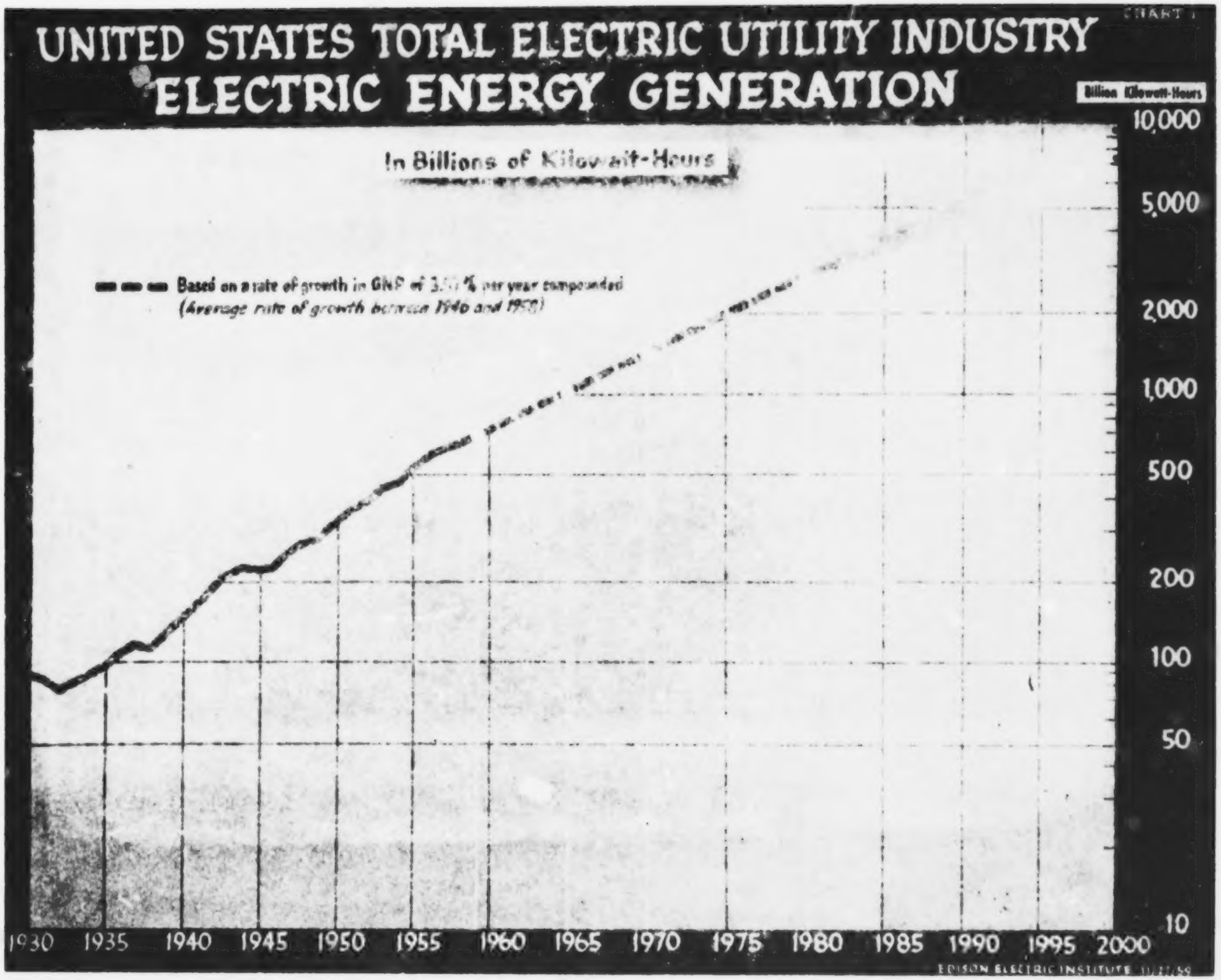
CHART 1



compared with population estimates of the U.S. Bureau of the Census.

Kilowatt-hour sales on a national basis are influenced by the level of business activity, the growth in the economy, and population. In analyzing the historical trends in kilowatt-hour sales, it was found that positive relationships exist between kilowatt-hour sales in the various customer classifications and components of the gross national product in constant dollars, and the Federal Reserve Board index of industrial production. Therefore, by a series of correlations [1] it was found that long-term estimates of kilowatt-hour sales could be derived with a reasonable degree of confidence from estimates of the growth in the national economy as measured by gross national product in constant 1954 dollars.

Two such estimates were made, one assuming GNP (in constant dollars) will continue to grow at the 3.57 percent average annual rate of the past 12 years (1946–58) and the other assuming an average annual increase in GNP of 3 percent per year, which is approximately the average rate of growth in GNP (in constant 1954 dollars) over the past 50 years.

The aggregate kilowatt-hour generation as estimated by the task force by FPC regions coincided with the projection of kilowatt-hours based on the average rate of growth in GNP between 1946 and 1958 3.57 percent per year compounded. Therefore, this projection of GNP was adopted for the purpose of estimating per capita sales by customer classifications for the years 1959, 1970, and 1980.

Chart I on the following page shows projected electric energy generation from 1959 to 1980.[2] This projection is based on a 3.57 percent rate of growth in GNP. To project onto the year 2000 involves a great deal of speculation. Studies of the institute indicate that in the year 2000 total output will range between 6 trillion and 10 trillion kilowatt-hours, depending on the rate of growth of the national economy and the rate at which new energy uses are introduced, especially electric space heating. Sales should be in about the same proportion among types of customers as in 1980, with a possible increase in the domestic classification.

The institute estimates for the total United States, based on the previously described studies, are shown in table I.

TABLE I.—*Peakload, capability, and energy requirements, total United States, projected by Edison Electric Institute*

	1959	1970	1980
Sales (billion kilowatt-hours):			
Domestic (residential and rural)	184	450	920
Industrial and commercial	415	820	1,490
Other	26	40	50
Total sales (billion kilowatt-hours)	625	1,310	2,460
Output (billion kilowatt-hours):			
Electric utility industry	707	1,481	2,795
Self-generation [1]	83	92	100
Total United States (billion kilowatt-hours)	790	1,573	2,895
Load (thousand megawatts):			
Electric utility industry	129	265	501
Self-generation [1]	16	18	20
Total United States	145	283	521
Capability (thousand megawatts):			
Electric utility industry	[2] 165	[3] 305	[3] 576
Self-generation [1]	18	[3] 21	[3] 23
Total United States	183	326	599

[1] Generation of energy by an industrial plant for its own use.

[2] Task force figure of 159,000 megawatts represents about a 97-percent coverage of the total electric utility industry.

[3] Based on an assumed margin of 15 percent which is not purported to be a required reserve, but is considered to be adequate, on the average. Required reserve margins vary from system to system depending on operating characteristics of the system.

Population estimates were based on estimates by the Census Bureau for the years 1960, 1965, 1970, 1975, and 1980.

Energy use per capita based on these projections is shown in table II.

TABLE II.—*Energy use per capita, total United States, projected by Edison Electric Institute*

	1959	1970	1980
Estimated population (millions)	176	208	245
Kilowatt-hour sales per capita:			
Domestic (residential and rural)	1,044	2,161	3,749
Industrial and commercial	2,354	3,939	6,071
Other	147	192	204
Total sales per capita	3,545	6,292	10,024
Kilowatt-hour output per capita:			
Electric utility industry [1]	4,010	7,113	11,390
Self-generation	471	142	407
Total output per capita	4,481	7,255	11,797

[1] Difference between total sales per capita and output per capita of electric utility industry represents losses incurred in serving utility customers. Self-generation sources are not subject to sale and, therefore, are not included in the sales per capita figures.

On the basis of a population of 340 million, the per capita range in the year 2000 would be 17,600 to 29,400 kilowatt-hours.

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[1] Household and farm sales show a definite correlation with disposable personal income; commercial sales correlate with personal consumption expenditures for services; and industrial sales correlate with the FRB index of industrial production all of which, in turn, can be correlated with GNP in constant dollars.

[2] Generation was estimated from total sales by adding an estimated amount for losses, company use, etc.

Table III gives peakloads in megawatts and energy in million kilowatt-hours for the years 1959, 1970, and 1980 for the total industry by FPC regions.

TABLE III.—*Peakloads and energy requirements, total electric utility industry,*[1] *forecasted by Edison Electric Institute*

FPC region	1959		1970		1980	
	Peakload (megawatts)	Energy requirements (million kilowatt-hours)	Peakload (megawatts)	Energy requirements (million kilowatt-hours)	Peakload (megawatts)	Energy requirements (million kilowatt-hours)
I	27,312	138,846	49,815	268,468	82,851	458,776
II	23,839	140,644	45,507	267,200	84,093	493,600
III	23,909	138,220	55,105	310,093	110,209	612,062
IV	[2] 14,744	80,649	[2] 29,147	151,757	[2] 53,125	276,768
V	[2] 14,185	69,967	[2] 40,315	197,023	[2] 88,580	440,406
VI	2,613	13,102	7,020	35,583	14,791	72,425
VII	9,867	57,021	19,500	108,624	35,700	193,158
VIII	[2] 12,139	68,465	[2] 25,353	142,318	[2] 44,445	247,665
Total	[3] 129,000	706,914	[3] 265,000	1,481,066	[3] 501,000	2,794,860

[1] Includes investor-owned systems, Federal and non-Federal Government agencies and cooperatives. Does not include industrial, mine, railway electric powerplants, and isolated plants in institutions, hotels, apartment houses, office buildings, etc.

[2] Designates a summer peak.

[3] This total peakload is not the sum of the individual regional peaks because the regional peaks do not necessarily all occur at the same time whereas the total peakload shown is the estimated annual maximum for the country as a whole.

The manner in which the total industry load is being supplied, by regions, for the year 1959, is shown in table IV.

TABLE IV.—*Capability types used to supply total electric utility industry load,*[1] *estimated by Edison Electric Institute, 1959*

FPC region	Peakload (megawatts)	Capability at time of regional peak, megawatts				
		Conventional thermal	Nuclear thermal	Hydro [2]	Other sources [3]	Total
I	27,312	29,074	----------	3,375	472	32,921
II	23,839	29,543	60	471	241	30,315
III	23,909	22,331	----------	6,425	(48)	28,708
IV	[4] 14,744	16,550	----------	835	200	17,585
V	[4] 14,185	16,582	----------	1,072	285	17,939
VI	2,613	2,524	----------	1,194	36	3,754
VII	9,867	1,038	----------	11,182	193	12,413
VIII	[4] 12,139	9,030	5	5,382	55	14,472

[1] Includes investor-owned systems, Federal and non-Federal Government agencies and cooperatives. Does not include industrial, mine, railway electric powerplants, and isolated plants in institutions, hotels, apartment houses, office buildings, etc.

[2] Median hydro conditions.

[3] Other sources include firm capability available to the region from nonutility facilities within the region plus firm receipts from outside the region minus firm commitments to others outside the region.

[4] Designates a summer peak.

These capability figures for the total industry for the year 1959 are available from the semiannual survey of the Electric Power Survey Committee of the Edison Electric Institute.

Forecasts for investor-owned utility companies

As previously indicated, the institute does not have complete information on how power suppliers other than the investor-owned utility companies will expand their capacity requirements in the future years of 1970 and 1980. Consequently, the following section on recommended means of serving future loads has been confined to investor-owned systems.

Before discussion the anticipated ways (conventional, nuclear, and hydro) that the investor-owned systems propose to use in serving their loads in 1970 and 1980, however, it is well to describe briefly factors that affect the installation of capacity and load growth in the various FPC regions. It should be noted that the individual regional peakloads occur in both the summer and December periods. Thus, peakloads are customarily reported on a summer and December basis, but it must be realized that local conditions can alter the exact time of the peak for individual systems.

New capacity is always scheduled for installation just ahead of the peakload period for the year. Thus, companies with summer peakloads plan their capacity additions for initial operation in the spring, while companies with December peaks plan to have their new capacity additions go into service in the fall. An inspection of table V at the end of this section indicates that the estimated rate of load growth is by no means uniform as between the regions. The resulting figures are related to the probable population shifts to the southern, southwestern, and western sectors of our country and the nature of anticipated economic changes.

These growing loads have an effect on the type of capability installed in the future. For instance, hydro capability may currently provide cheaper power than thermal means at the load center in certain sections of the country. But this situation may not continue as loads increase and the number of economic hydrosites decrease.

While the electric industry makes long-range forecasts extending over 10 years or more, programing of specific plans, design, and actual construction falls within a 5-year range. Thus, actual construction closely precedes and is related to the growth patterns in any region as they are about to take place. The result is a longstanding record by the investor-owned utilities of anticipating and adequately meeting the electric power needs of the public served.

The following region-by-region analysis of forecasted peakloads and capability indicates the influence of these and other factors.

Region I

This region consists of the New England States, New York, New Jersey, Delaware, the District of Columbia, and portions of Maryland and Pennsylvania. It embraces the high-density load areas of Boston, New York City, Philadelphia, Baltimore, Washington, and the Niagara frontier, as well as lower density areas elsewhere in the region.

The investor-owned companies in region I have now and will continue to have a December peak although their estimated summer peak will be almost equal to the estimated December peak in both 1970 and 1980. The high summer peaks of companies in metropolitan areas have a strong influence on this situation. Peakload for the investor-owned companies in this region is estimated to be about 48,961 megawatts in 1970 and approximately 81,821 megawatts in 1980. These regional peakload figures are the highest forecasted for any region although the rate of growth in region I is less than the load growth rate in other regions.

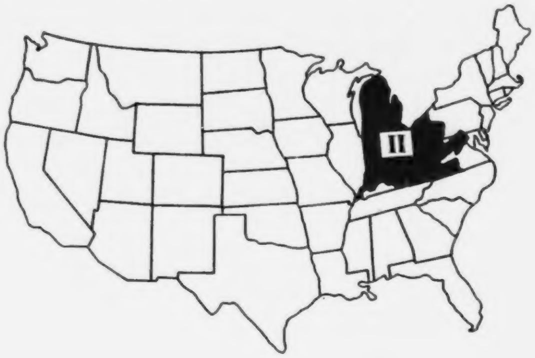
To serve these peakloads it is estimated that the investor-owned companies will have 58,490 megawatts of capability in 1970 and 96,854 megawatts in 1980. A substantial portion of the capability in both of these years probably will be provided by thermal means. In 1959 the peakload for the investor-owned systems was about 26,813 megawatts and the capability, including firm purchases to serve it, was about 32,361 megawatts. Investor-owned companies in the region are expected to obtain approximately [illegible] percent of their capability from other sources in 1970 and about 2.4 percent from other sources in 1980. Most of this represents hydro capability already under contract with the New York State Power Authority.

Region II

Utilities in this highly industrialized area serve many basic industries. The region has a fairly uniform load density. The States of Michigan (lower peninsula), Indiana, Ohio, West Virginia and parts of Virginia, Pennsylvania, Kentucky, Maryland, and Tennessee comprise this region. Under the revised boundaries recently established by FPC this region now includes FPC power supply area 19 which previously was included in region III. Companies serving the southern portion of this area are experiencing summer peaks due to extensive use of air conditioning. However, the active and successful promotion of electric heating in the region should be the more dominant factor in the future so that the investor-owned systems in the region as a whole will probably continue to have the December peaks they now experience. But the difference between December and summer peaks of the investor-owned systems will decrease percentagewise in future years.

The estimated 1959 investor-owned systems' December peakload of 23,160 megawatts was served with a regional capability of approximately 29,335 megawatts. In 1970 the December peak load is expected to be about 44,357 megawatts and the capability to serve it about 52,652 megawatts. Similar probable figures for 1980 are 81,593 megawatts peakload in December and 96,128 megawatts capability.

The investor-owned systems in the region have only a small amount of hydro capability. It now

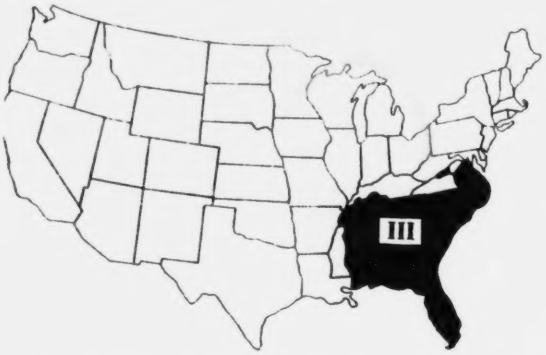


provides about 1½ percent of the capability in the region. Even this small amount represents most of the feasible hydro capable of development in the region. Thermal units, therefore, will provide most of the required capability in the future.

The estimated 1959 gross margin [3] is unusually high for this region and is due to the installation of capability already underway in 1958 and 1959 at a time when load growth was slowing down due to the recession last year and the steel strike. The gross margins predicted for 1970 and 1980 are expected to be lower and in keeping with efficient utility operations although it must be realized that actual economic conditions in the years in question may produce different margin conditions.

Region III

This region covers an area from the Potomac River to the tip of Florida and from the Atlantic Ocean west almost to the Mississippi River. Although it includes most of Tennessee, this portion of the State and parts of Mississippi, Alabama, Georgia, and Kentucky embracing the service area of the Tennessee Valley Authority have been eliminated from this analysis.



This is one of the fastest growing sectors of the country. By 1980 the regional peakload of the investor-owned companies is expected to be almost six times what it is now. To serve this regional load, both now and in the future, the investor-owned utilities will rely mainly on thermal steamplants. However, the utilities in this region will continue to develop economically feasible hydro sites. It is estimated that by 1980 hydro capacity in this region will have increased 127 percent over what it now is.

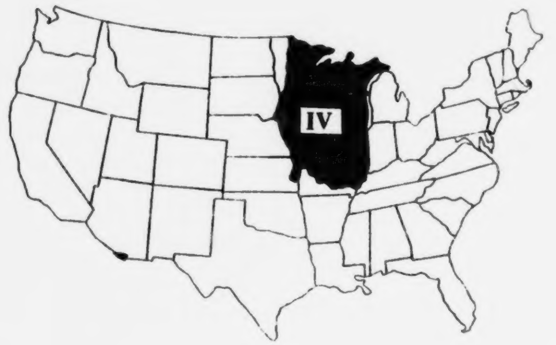
The regional peak of the investor-owned companies probably will change to a summer peak in 1970 and remain a summer peak in the year 1980. This is mainly due to the expected larger influence of the Florida sector on the total regional peak in the years to come. Although Florida now has a December peak it is rapidly changing to a summer one because of the influence of air conditioning and this, together with the influence of air conditioning in other sectors of the region, probably will change the peak conditions in this region as indicated above.

In 1959 the combined December peakload for the investor-owned systems in this region was about 12,634 megawatts and the investor-owned companies served this load with a total capability of about 14,917 megawatts. In 1970 similar figures are expected to be 34,948 megawatts peakload and 39,634 megawatts of capability. In 1980 the figures are expected to be 73,016 megawatts of peakload and 81,190 megawatts of capability.

Region IV

This region consists of the States of Illinois, Wisconsin and parts of Minnesota, Iowa, Missouri, and Michigan (Upper Peninsula). The utilities in region IV basically have two types of loads. One is a high-density load of the industrialized metropolitan areas of Chicago, St. Louis, Milwaukee, Minneapolis-St. Paul, and Kansas City. The other type of load is predominantly an agricultural one prevalent in the remaining sectors of the region.

The investor-owned systems in region IV had approximately equal summer and December peak loads in 1959. It is expected that the summer



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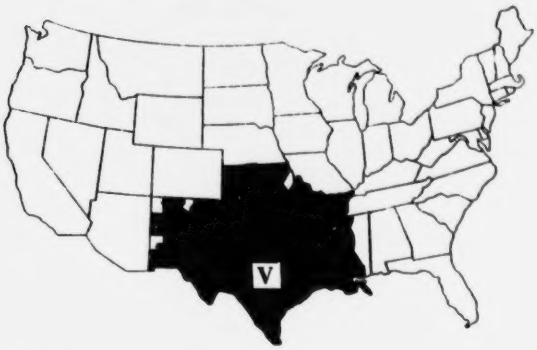
[3] Gross margin represents the difference between capability and peakload. Gross margin, therefore, should be of sufficient magnitude to provide for scheduled maintenance, low-water conditions at hydroplants, emergency outages and system operating requirements if practical operating conditions are to be maintained.

peak will become predominant in the future. There is very little hydro capability in this region and substantially all of it has been developed. Some pump storage hydro capacity is being planned. Thermal generation is expected to be the main source of energy.

The 1959 investor-owned systems summer peak load was about 14,160 megawatts. Serving it was a capability of about 16,801 megawatts. Similar figures for 1970 are estimated to be 28,406 megawatt peak load and 32,319 megawatts of capability; for 1980 51,774 megawatt peak load and 57,807 megawatt capability.



Region V

This region is comprised of the Southwestern States of Texas, Oklahoma, Louisiana, Arkansas, Kansas, most of New Mexico, and parts of Missouri and Mississippi. It is probably the fastest growing region of the United States as far as the electric utility industry is concerned. The regional peak loads of the investor-owned companies are expected to increase almost threefold by 1970 and be slightly more than six times what they are today by the year 1980. This region experiences a definite summer peak. However, in certain sectors of the eastern part of this region this peak extends on through into October because of the large use of electricity for irrigation pumping purposes.

The estimated gross margin of investor-owned systems in this region was about 25 percent in 1959. This high margin is due to unprecedented cool weather in the area last summer which resulted in abnormally low summer peaks. Because of the definite summer peak situation in this region capability additions are made in the spring of the year. As was previously indicated, the main concern of the utilities is to have the capability for the necessary peaks. For this reason there is generally a large margin of capability during the winter months in this region.

In 1959 the investor-owned utilities in this region had a summer peak of about 13,044 megawatts and had about 16,329 megawatts of capability to serve this peak. In 1970 the utilities are expected to have 41,896 megawatts of capability, most of which will be thermal capacity, to serve a summer peakload of 37,063 megawatts. In 1980 thermal capability will still continue to be the main source of generation and the total capability in this region is expected to be 92,223 megawatts available to serve summer peakload of 81,015 megawatts.

Region VI

This region includes the States of North Dakota, South Dakota, Nebraska, Wyoming, and Colorado, and parts of Minnesota, New Mexico, and Montana. This region of rugged mountains and great plains is sparsely inhabited. Because Nebraska is served by State agencies, this area was eliminated from the analysis. Although this region is among the largest in terms of area in the United States, its peakload presently is only 2 percent of the national total. It has one of the largest growth rates in the country and its expected peakload in 1980 is estimated to be almost six times what it is now. However, this will still only represent about 3 percent of the national total.

The investor-owned companies in the region rely mainly on conventional thermal generation to carry their loads. The investor-owned companies' regional peakload occurs in December and probably will continue to do so in 1970 and 1980.

This year the December peakload was about 1,316 megawatts and there was adequate capability of about 1,716 megawatts to serve it. Similar estimated figures for 1970 and 1980 are 3,301 megawatts of peakload and 3,880 megawatts of capability and 6,977 megawatts of peakload and 7,732 megawatts of capability.

Region VII

Region VII consists of the States of Idaho, Washington, Oregon, and most of the States of Montana, Utah, and a small portion of California. It encompasses an area that extends from the heavily populated western coastal areas to the more sparesly populated areas of Utah and Montana and from the more arid areas of Utah to areas of relatively high annual precipitation, with large streams suitable for hydroelectric development and other multipurpose uses.

It is expected that hydro will continue to be the main source of energy for the region until 1970. After that, conventional thermal capacity will take on added importance until in 1980 it is expected to represent about 32 percent of the total capability (including firm purchases) available to serve peakloads (it now represents about 16 percent of total regional capability).

In addition to having their own source of capability, the investor-owned companies in this region purchase substantial amounts of hydro capability under long-term contracts from other than investor-owned systems. This practice is expected to continue in the future.

Because this is a predominantly hydro area, the gross margin of capability can be lower than what is required for all steam systems. Experience has indicated that hydroelectric equipment is not subject to as many forced outages as equipment on thermal plants. It also does not require as much maintenance.

The 1970 capability figures have been forecast on the basis that there will be energy limitation to the area due to the availability of water. Thus, the investor-owned systems in the region will have surplus machinery in excess of what is shown for the gross margin, because of this energy limitation.

The region has a December peak and will continue to experience this condition in both 1970 and 1980. Hydro capability of the investor-owned systems, including long-term purchased power contracts, account for 84 percent of the total capability available to the investor-owned companies in 1959 and 88 percent of the total capability in 1970. However, in 1980 it probably will only account for 63 percent. The December peakloads in the years 1959, 1970, and 1980, respectively, are expected to be 5,026 megawatts, 10,800 megawatts, and 19,900 megawatts. Total capability of the investor-owned companies in the region serving this load is estimated to be 5,154 megawatts in 1959, 11,699 megawatts in 1970, and 21,303 megawatts in 1980.

Region VIII

This region consists of the States of Nevada, Arizona, and most of California. Most of Nevada and Arizona have few high-load density areas. However, the metropolitan areas of Los Angeles, San Francisco, San Diego, and Phoenix and the Central Valley area of California have high population and high-load density. This region has had its annual peakload in the summer. It is expected that summer peaks will continue into the future years of 1970 and 1980 and that the annual summer peak will be about 3 to 4 percent higher than the December peak. As in region V this summer peak sometimes extends into October because of the continuance of substantial irrigation loads and continuance of air-conditioning demands into the hot, dry fall months in many years. This load characteristic, therefore, leaves less time for maintenance of machines than would be the case in an area having a pronounced difference between summer, fall, and winter peaks.

The investor-owned utilities in this region have substantial long-term contracts for purchase of hydro capability from other than investor-owned systems, have a large amount of hydro capability of their own, but in the future will rely mainly on thermal capability in their major expansion plans.

The peakload of the investor-owned companies in this region was about 8,907 megawatts in 1959, and is estimated to be 18,707 megawatts in 1970 and 32,386 megawatts in 1980. The investor-owned companies had 10,714 megawatts of capability in 1959 and are expected to have 22,353 megawatts in 1970 and 39,090 megawatts in 1980 to serve these peakloads.

Summary of peakloads and capability

Table V in the next column summarizes these peakloads and indicates the capability of the investor-owned companies at the time of these peakloads segregated into the different types of capability.

TABLE V.—*Capability types used to supply investor-owned system loads 1959, 1970, and 1980, forecasted by Edison Electric Institute*

1959

Region	Peakload (megawatts)	Capability at time of regional peak (megawatts)				
		Conventional thermal	Nuclear thermal	Hydro [1]	Other sources [2]	Total
I	26,813	29,010	----------	2,640	711	32,361
II	23,160	28,736	60	460	79	29,335
III	12,634	12,634	----------	1,945	338	14,917
IV	[3] 14,160	16,006	----------	763	32	16,801
V	[3] 13,044	15,841	----------	98	390	16,329
VI	1,316	1,521	----------	58	137	1,716
VII	5,026	834	----------	3,620	700	5,154
VIII	[3] 8,907	7,175	5	2,902	632	10,714

1970

Region	Peakload (megawatts)	Conventional thermal	Nuclear thermal	Hydro [1]	Other sources [2]	Total
I	48,961	49,163	3,140	3,847	2,340	58,490
II	44,357	50,565	565	822	700	52,652
III	[3] 34,948	35,063	460	3,513	598	39,634
IV	[3] 28,406	30,879	242	1,109	89	32,319
V	[3] 37,063	38,540	2,150	106	1,100	41,896
VI	3,301	3,658	----------	57	165	3,880
VII	10,800	1,432	----------	7,156	3,111	11,699
VIII	[3] 18,707	16,117	1,162	3,393	1,681	22,353

1980

Region	Peakload (megawatts)	Conventional thermal	Nuclear thermal	Hydro [1]	Other sources [2]	Total
I	81,821	81,827	7,990	4,697	2,340	96,854
II	81,593	89,260	5,090	892	886	96,128
III	[3] 73,016	73,190	3,110	4,423	467	81,190
IV	[3] 51,774	51,259	5,192	1,109	247	57,807
V	[3] 81,015	82,309	8,751	106	1,057	92,223
VI	6,977	7,171	300	57	204	7,732
VII	19,900	6,832	1,000	10,258	3,213	21,303
VIII	[3] 32,386	24,874	7,467	3,384	3,365	39,090

[1] Median hydro conditions.

[2] Other sources include firm capability available to the region from other than investor-owned systems and nonutility facilities within the region plus firm receipts outside the region minus firm commitments to others outside the region.

[3] Designates a summer peak.

II. PRODUCTION COSTS OF CONVENTIONAL THERMAL PLANTS

The select committee has requested data on the capital and operating cost of new generating units to be placed in service in 1970 and 1980. In complying with the committee's request, the task force found it necessary first to decide upon the treatment of considerations of a general economic nature; second to determine a "representative unit"; and third, to recognize differences among the various FPC regions.

The important consideration from the point of view of national policy is the ability of the electric utility industry to meet its future energy obligations to the public without sharp increases in real costs of production. In other words, can the electric utility industry look forward to a continuation of the gains in efficiency and the consequent improvements in productivity that has characterized its performance in the past? The answer to this question depends upon the availability of fuel supplies, the growth in the demand for energy which will in turn permit the economies associated with larger units and, perhaps most of all, the expected advances in the technology of electric generation.

Inasmuch as changes in the general price level are irrelevant to a discussion of real costs, all data are stated in terms of current (1959) dollars. Wage rates were held constant because changes in real wage rates would certainly pervade the entire economy and would introduce a distortion in comparing present with future efficiency in the art of producing electric power. Fuel costs were assumed to remain unchanged in view of the larger reserves of suitable fuels which are expected to be adequate to fill the needs of the economy in 1970 and 1980. Many costs were calculated on a current basis because of the difficulties of estimating interest-rate and tax-rate changes so far into the future. The following estimate, therefore, reflects mainly the technological advances in the art of electric generation, including the trend toward larger units, improved efficiency of high temperatures and steam pressures, and new manufacturing processes.

The determination of a "representative unit" resulted from an examination of the likely course of development during future years. Some units will be additions to existing plants, some will be the first units in new plants, while some will be the first two or three units of a new plant. In order to avoid citing either the low incremental cost of adding units, or the higher cost of initial units, including site development expenses, the task force took both factors into consideration. The result is the estimated cost of a multiunit plant thus averaging the costs of initial and additional units. The "representative unit" epitomizes the composite characteristics of each FPC region and may be considered the typical plant, as to size and type, that will be constructed in the region in 1970 and 1980. Obviously, the actual construction of plants will reflect variations from the "representative unit" dependent upon local circumstances. In fact, any one of the regional component costs can vary as much as plus or minus 15 percent for a specific plant at a specific point in the region as compared with another plant in the same region.

In determining the "representative units" within a specific region such data as fuel costs, construction costs, climatic conditions, and sources of cooling water were taken into consideration. The result, of course, was considerable variation among these factors for the different regions.

The capability requirements and cost factors were examined in each of the FPC regions by engineers familiar with the utility systems in the region. As a result of this analysis, composite capability and cost figures were developed from the weighted average of all the possible units that might be installed in various locations within the specific region in or about the years 1970 and 1980. These representative figures are in some cases necessarily hypothetical figures and are not meant to infer that the prevalent costs and capability figures necessarily coincide with the cited figures.

In determining the capital-charge component of total production cost, a uniform capital-charge percentage figure of 14 percent has been assumed to cover taxes, depreciation, and return.

All ratings and plant heat rates are based on net capability. Estimated capital costs enumerated in the following section of this report include all expenditures up to and including the high-voltage side of the step-up transformers. The estimated production costs for representative units going into service in 1970 and in 1980 for each FPC region are as follows:

Region I

Throughout the period of the study, coal will be the dominant fuel in the region. The use of oil and gas will be insignificant in comparison. The cost for delivered coal is estimated at about 35 cents per million B.t.u. The price will be somewhat higher in upper New England and lower for those plants near the coal fields of western Pennsylvania. The selected representative unit in 1970 has a capability of 350 megawatts, although some units will be as large as 900 megawatts and some smaller than the representative size. The installed cost of the 350-megawatt unit will be about $170 per kilowatt but may vary depending on location. For example, units built in and around metropolitan areas such as New York City have higher construction labor costs and thus higher total capital costs. The representative unit will have a heat rate of 8,900 B.t.u. per kilowatt. Being a newer and higher economy unit it will receive preferential loading and should operate the equivalent of 7,000 hours annually out of a total of 8,760 hours or about 80 percent of the time.

On the above basis, the capital charge will be 3.40 mills per kilowatt-hour, the fuel cost 3.12 mills per kilowatt-hour, the operation and maintenance cost 0.30 mill per kilowatt-hour. The total cost, sometimes referred to as bus bar costs, will be 6.82 mills per kilowatt-hour.

By 1980 the representative unit will be 450 megawatts in size, cost $160 per kilowatt, have a heat rate of 8,500 B.t.u. per kilowatt-hour and will also operate the equivalent of 7,000 hours annually at full load. Fuel costs should remain at about 35 cents per million B.t.u. Some units as large as 1,000 megawatts will be installed. The capital charge will be 3.20 mills per kilowatt-hour, the fuel cost will be 2.98 mills per kilowatt-hour, operation and maintenance costs will be 0.28 mill per kilowatt-hour, resulting in a total energy cost of 6.46 mills per kilowatt-hour.

Region II

Coal is the prevailing steamplant fuel and currently varies in cost from 17 cents per million B.t.u. along the lower Ohio River to 34 cents per million B.t.u. along the Great Lakes. A composite cost of 24 cents per million B.t.u. has been chosen as the 1970 and 1980 representative fuel cost for this analysis. Although some units as small as 150 megawatts and several as large as 500 megawatts will be installed, a 400-megawatt unit has been estimated as the representative unit of the region in 1970. Its capital cost is estimated to be $140 per kilowatt although there will be variations in this cost. The expected heat rate will be 8,800 B.t.u. per kilowatt-hour and the unit will be scheduled to operate the equivalent of 7,000 hours annually at full load.

As a result, the capital charge will be 2.80 mills per kilowatt-hour, the fuel cost will be 2.11 mills per kilowatt-hour, and the operation and maintenance cost will be 0.30 mill per kilowatt-hour. The total cost of energy delivered to the bus bar in 1970 will be 5.21 mills per kilowatt-hour.

In 1980 the estimated representative unit will increase to 600 megawatts although several units as large as 750 megawatts are contemplated. The estimated cost of the unit is $135 per kilowatt. The heat rate will decrease to 8,300 B.t.u. per kilowatt-hour and the unit will operate the equivalent of 7,000 hours at full load annually during the period around 1980.

Estimated production costs are 2.70 mills per kilowatt-hour for capital charges, 1.99 mills per kilowatt-hour for fuel (24 cents per million B.t.u.), and 0.28 mill per kilowatt-hour for operation and maintenance. Total cost of energy delivered to the bus bar is expected to be 4.97 mills per kilowatt-hour.

Region III

Fuel used in this area currently varies widely in both price and type. Coal is used in almost all sectors of the region. Oil, however, is prevalent in Florida. Gas is predominant in Mississippi and used on an interruptible basis at various locations in the eastern sector. However, it decreases in use as its price increases. But coal will be the dominant fuel by 1970 and currently varies in cost from 19 cents per million B.t.u. in Alabama to 33 cents per million B.t.u. in the Virginia-Carolinas. As previously indicated, the TVA service area has been eliminated from this analysis.

Although it is difficult to determine a representative fuel price for the region, a weighted average cost of 28 cents per million B.t.u. based on 1959 prices was chosen for both 1970 and 1980 conditions. The selection of a representative unit was simpler as the general size contemplated for operation in 1970 is 325 megawatts, although some units of 450–500 megawatts are in prospect. The estimated cost of the representative unit was determined to be $130 per kilowatt. The heat rate of the unit will be in the order of 8,850 B.t.u. per kilowatt-hour. Because of variations in type and sizes there will be both higher and lower costs at different locations. Considerable hydro capacity exists in this region and can be scheduled for peak periods. This situation should continue in the future. Thus, the representative unit can be scheduled for the equivalent of 7,200 hours full-load annual operation in both 1970 and 1980.

Based on the above premises, the expected representative production cost of units coming into service in 1970 will be 2.53 mills per kilowatt-hour for capital charges, 2.48 mills per kilowatt-hour for fuel and 0.27 mill per kilowatt-hour for operation and maintenance. The total cost delivered to the bus bar will be 5.28 mills per kilowatt-hour.

In 1980 the representative unit will probably increase to 500 megawatts although some units of 750 megawatt size as well as smaller ones will be installed at certain locations. The expected heat rate will be 8,800 B.t.u. per kilowatt-hour. The estimated average capital cost of the unit will be $120 per kilowatt. Total bus bar costs will be 5.04 mills per kilowatt-hour. The component parts of this cost will be 2.33 mills per kilowatt-hour for capital charges, 2.46 mills per kilowatt-hour for fuel (28 cents per million B.t.u.) and 0.25 mill per kilowatt-hour for operation and maintenance.

Region IV

The determination of representative figures for conventional steam production costs in 1970 and 1980 for this region was more difficult than in other regions. As previously indicated, the variations in load and population densities are unusually great. Significant variations in construction labor costs as well as fuel types and prices exist. Coal prices vary from 17 cents per million B.t.u. in southern Illinois to 32 cents per million B.t.u. on Lake Michigan and 36 cents per million B.t.u. in inland areas. Gas is also used in various areas with prices ranging from 23 to 32 cents per million B.t.u. Many interconnected companies, small and large, serve the territory. It is intended that the representative units chosen together with their associated fuel costs will reflect as nearly as possible the weighted average total production cost for the region as a whole.

The hypothetical 1970 unit will be 325 megawatts in size, cost about $135 per kilowatt, have a heat rate of 9,000 B.t.u. per kilowatt-hour and will operate the equivalent of 7,000 hours annually on a full-load basis. A coal cost of 27 cents per million B.t.u. should be representative for the region. The component production costs will be 2.7 mills per kilowatt-hour for capital charges 2.43 mills per kilowatt-hour for fuel and 0.26 mills per kilowatt-hour for operation and maintenance, resulting in a total energy cost of 5.39 mills per kilowatt-hour.

Although this selected unit reflects the best judgment to determine average production costs, it should be recognized that it is the intent of operating companies, particularly those in metropolitan areas, to take full advantage of the availability of larger units. Units as large as 450 to 600 megawatts with associated improved heat rates are expected to be installed in the region by 1970.

The representative unit selected to reflect average regional production costs in 1980 was 425 megawatts in size with a heat rate of 8,800 B.t.u. per kilowatt-hour. The estimated capital cost of this unit is $130 per kilowatt and it will burn coal costing 27 cents per million B.t.u. The representative unit in 1980 also will operate the equivalent of 7,000 hours annually on a full-load basis. Total production cost will probably be 5.23 mills per kilowatt-hour, composed of 2.6 mills per kilowatt-hour for capital charges, 2.38 mills per kilowatt-hour for fuel and 0.25 mills per kilowatt-hour for operation and maintenance.

Units ranging from 450 to 750 megawatts are expected to be installed by 1980 in order to serve large metropolitan area loads.

Region V

The combination of low-cost gas and outdoor construction has permitted utilities in this region to produce power more cheaply than utilities in most other regions in the United States.

In keeping with the assumptions made in estimating future costs in other regions, investment costs for this region are given in terms of 1959 dollars. The representative price of fuel (gas) will be about 20 cents per million B.t.u. for both 1970 and 1980 at 1959 prices.

The heat rates of units installed in this section of the country normally have not been as low as the heat rates of units installed where fuel prices are higher. The additional incremental expense of obtaining a more efficient cycle has not been deemed economical because of the low-cost fuel and the inherent lower efficiency of gasfiring. If by 1970 and 1980 the cost of fuel in this region in terms of these future prices is appreciably higher the heat rates of the units installed in this region in 1970 and 1980 will probably be lower than what they are now justifying an increase in capital investment. All investment costs have been given in terms of 1959 dollars and this possible occurrence has not been taken into consideration in this report.

The representative unit for region V in 1970 will be about 350 megawatts in size. It will cost $125 per kilowatt on a 1959 dollar basis, operate the equivalent of 7,000 hours at full load during the year, have a heat rate of 10,000 B.t.u. per kilowatt-hour and burn gas costing 20 cents per million B.t.u. There will be some use of coal, but gas will be the cheaper and more dominant fuel.

Total energy costs at the bus bar will be 4.7 mills per kilowatt-hour. A breakdown of this charge shows 2.5 mills per kilowatt-hour for capital charges, 2 mills per kilowatt-hour for fuel and 0.2 mills per kilowatt-hour for operation and maintenance. The favorable climate and the predominance of gasfired plants will be important factors in this low operation and maintenance cost.

By 1980 similar total energy charges for a 500 megawatts, 1980 representative unit will be 2.2 mills per kilowatt-hour for capital charges, 1.9 mills per kilowatt-hour for fuel, 0.2 mills per kilowatt-hour for operation and maintenance expenses, and 4.3 mills per kilowatt-hour for total energy costs.

The capital cost for this unit assumed to be gasfired will be about $110 per kilowatts and fuel cost will be approximately 20 cents per million B.t.u.

It will operate the equivalent of 7,000 hours per year at full load and have a heat rate of 9,500 B.t.u. per kilowatt-hour.

It should be recognized that large sparsely settled areas exist between the load centers of New Mexico and El Paso, Tex., and the denser areas in the remainder of the region. Thus, it would be appropriate to install smaller units in these remote load center areas. In the denser load center areas units as large as 400 megawatts are expected to be installed in 1970 and units as large as 800 megawatts are expected to be installed in 1980.

Region VI

North Dakota, South Dakota, and the eastern portion of Montana in region VI have little conventional steam capacity. They are served generally by Federal hydro developments. Most of of the thermal capacity in this region is installed in the corridor extending from Casper, Wyo., through Cheyenne and Denver to Pueblo, Colo. For this reason the representative sizes and costs for region VI are based mainly on the projections of the utilities operating in this area.

At present, most of the powerplants in Colorado use both gas and coal with gas the dominant of the two fuels. However, the reverse is expected in 1970 with coal being the dominant fuel with a representative price of about 24 cents per million B.t.u.

The representative thermal unit for region VI at that time will be about 150 megawatts with an installed cost of approximately $153 per kilowatts. The heat rate for this unit will be about 9,500 B.t.u per kilowatt-hour. Because of the availability of some secondary hydro in the region the load factor on the thermal plants will probably be lower than in other regions for the 1970 period. The equivalent of 5,300 hours of annual full-load operation has been assumed.

Thus, 1970 representative costs become 6.74 mills per kilowatt-hour for total energy costs, 4.04 mills per kilowatt-hour for capital charges, 2.28 mills per kilowatt-hour for fuel and 0.42 mills per kilowatt-hour for operation and maintenance expenses.

Coal at a price of 24 cents per million B.t.u. will continue to dominate the fossil fuel picture in 1980 and the representative thermal units at that time will probably still continue to operate at a low load factor—the equivalent of 5,500 hours of yearly full-load operation has been assumed.

The representative unit size will increase to about 225 megawatts, its cost will decrease to about $142 per kilowatts when compared with the 1970 representative figure, and it is expected to have a heat rate of 9,000 B.t.u. per kilowatt-hour.

Total bus bar energy costs will be approximately 6.14 mills per kilowatt-hour. Components of this cost are 3.61 mills per killowatt-hour for capital costs, 2.16 mills per kilowatt-hour for fuel and 0.37 mills per kilowatt-hour for operation and maintenance.

Units as large as 200 megawatts are expected to be installed by 1970 and as large as 300 megawatts by 1980.

Region VII

With the exception of Utah, the present major source of power supply for the region is hydroelectric. Coal-fired steamplants are the principal source of energy in Utah. In addition, there are a few older oil-and-gas-fired plants in the coastal areas held on a standby basis. It is expected that hydro will continue to be the principal source of power supply until the mid-1970's. Steam electric development prior to the mid-1970's will be confined to special areas and will be principally dictated by local area conditions and the desire to produce the cheapest energy by combining the lower capital cost of a steam electric plant with the utilization of secondary hydro energy, otherwise wasted, as fuel replacement.

With the completion of major hydro developments, the area energy requirements will be supplied by fossil fuels, principally coal and nuclear power. Large deposits of coal are located in Utah and in the adjacent State of Wyoming, with sizable amounts in the State of Washington and with some in Oregon. The conventional coal-fired steam electric plants located inland will be operated in coordination with the hydroelectric supply of the area and with nuclear and oil-fired plants located in the coastal areas where fuel costs will be the highest.

Fuel costs in 1959 ranged from a low of 19 cents per million B.t.u. in the Utah area to 40 cents per million B.t.u. in the coastal areas.

Representative fuel costs in 1970, when new steam electric generation will be principally confined to the region's fuel areas, will be 19 cents per million B.t.u. The representative unit size will be approximately 200 megawatts and its cost will be $165 per kilowatt. The heat rate will be 9,600 B.t.u. per kilowatt-hour and it is estimated that the unit will operate an equivalent of 7,000 hours per year at full load.

The representative total energy cost will be 5.45 mills per kilowatt-hour. The components of this cost will be 3.3 mills per kilowatt-hour for capital charges, 1.83 mills per kilowatt-hour for fuel, and 0.32 mill per kilowatt-hour for operation and maintenance expenses.

By 1980, when the increasing electric demands of the entire region must be supplied from thermal units, it is expected that conventional steam units up to 1,000 megawatts may be installed, with the regional representative units considered at 500 megawatts. Such a unit is expected to cost $125 per kilowatt and have a heat rate of 8,500 B.t.u. per kilowatt-hour. Fuel costs are estimated at 30 cents per million B.t.u. and the unit would operate the equivalent of 6,800 hours per year at full load.

The representative 1980 total energy cost for the 500-megawatt unit would be 5.40 mills per kilowatt-hour, made up of 2.57 mills per kilowatt-hour for capital charges, 2.55 mills per kilowatt-hour for fuel costs and 0.28 mill per kilowatt-hour for operation and maintenance costs.

Region VIII

This region is a two-fuel area. Both gas and oil are used for electric power generation in substantial quantities. This practice should continue through 1970 and 1980. For the purpose of this report, a price of 32 cents per million B.t.u. based on 1959 prices has been selected as a composite of all probable fossil fuel-prices in this region for both the years 1970 and 1980.

Because of the relatively high cost of fossil fuels in this region, the lack of a coal supply in the immediate vicinity of the major load centers and the increase in demand by other users of gas and oil, it is expected that nuclear plants will become an important source of energy in this region by 1970.

A representative unit size of 325 megawatts (conventional) was selected as a compromise between the requirements of the high-population and load-density areas and the large undeveloped areas for 1970 conditions. It was estimated to cost $145 per kilowatt and have a heat rate of about 8,700 B.t.u. per kilowatt-hour. It should be noted that smaller units will be built in remote areas and units as large as 500 megawatts will be installed in California.

Hydroelectric power will continue to be an important factor in this region. The representative unit will run only the equivalent of 6,500 hours during the year at full load because of steam displacement by hydro energy during certain seasons of the year. Busbar energy costs will be about 3.13 mills per kilowatt-hour for capital charges, 2.78 mills per kilowatt-hour for fuel, 0.33 mill per kilowatt-hour for operation and maintenance expenses, and 6.24 mills per kilowatt-hour for total energy cost at the plant.

The representative conventional thermal unit in 1980 will be approximately 450 megawatts in size, will cost about $140 per kilowatt, will operate the equivalent of 6,500 hours annually at full load, and will have a heat rate of 8,700 B.t.u. per kilowatt-hour. Busbar energy costs will probably amount to 3.01 mills per kilowatt-hour for capital, 2.78 mills per kilowatt-hour for fuel, and 0.3 mill per kilowatt-hour for operation and maintenance. These component costs add to 6.09 mills per kilowatt-hour at the plant.

III. NUCLEAR POWER

The expected installation of nuclear capacity by 1970 and 1980 in the several regions by the investor-owned systems was shown in table V. Because of the present state of the art, any long-range forecast must necessarily be speculative. The industry is aware of the importance of developing this new form of energy as rapidly as it is feasible to do so. Evidence of this is the participation of so many of the investor-owned utilities in the development of nuclear projects now in various stages of study, design, construction, and operation—131 of these companies are engaged in this effort. The projects in which electric power companies are presently participating will have an ultimate combined capacity of about 1,400,000 kilowatts and will require an estimated expenditure by the companies of more than $570 million on these projects alone.

Experience gained from these projects should provide by 1965 a better perspective for future development. In the absence of this experience, the industry can only rely on its best judgment and the views of authorities in the field. The national objective of our country is to achieve competitive nuclear power in the higher cost fuel areas of the United States within 10 years. The investor-owned utility industry subscribes to this objective. Many new and improved designs of nuclear plants are under development. Fuel for such plants is also being improved. However, the cost of power is still high, but the margin over fossil fuel power is narrowing. The rate at which nuclear power will gain on fossil fuel is difficult to predict but the estimates in table V are based on the best opinions available at the moment.

By 1970 about 7,700 megawatts of nuclear capability is projected for use in serving the loads of the investor-owned utility systems. This will represent about 3 percent of 1970 total capability projected by the investor-owned systems. Similar estimated figures for 1980 are 38,900 megawatts of nuclear capability representing about 8 percent of the total investor-owned capability in service.

As would be expected, substantial amounts of nuclear capability will probably be installed in the high fossil-fuel cost sections of the country. For example, in 1970 it is expected that about 7 percent of the investor-owned capability in the New England area will probably be nuclear. By 1980 this percentage is expected to be 16. Comparable percentages of nuclear capability in region VIII are expected to be 5.2 percent in 1970 and 19.2 percent in 1980.

Should future development increase the competitive position of nuclear power, nuclear capability would merely displace future projected conventional thermal capacity and have only an insignificant influence on hydro development.

Until nuclear plants are developed for and operated at higher steam pressures and temperatures, they will require somewhat greater amounts of cooling water. However, ultimate comparable steam conditions will probably be achieved.

IV. HYDRO DEVELOPMENT

Capacity additions

Additional hydro capacity that investor-owned systems will probably install between now and 1980 is shown on a regional basis in table VI.

Table VI.—*Hydro capacity additions in megawatts, investor-owned systems, forecasted by Edison Electric Institute*

Region	1959-70	1971-80
I	1,041	978
II	575	150
III	1,639	800
IV	350	
V [1]		
VI [1]		
VII	2,915	2,821
VIII	699	
Total	7,219	4,749

[1] No hydro units planned for future installations.

A request was made by the select committee that estimates of the amounts of primary and secondary hydropower that can be developed in 1970 and 1980 be supplied. It is felt that no valid distinction can be made along these lines, and this report makes no attempt to provide such a distinction. Consideration of table V in which the hydro capability can be compared with the total at the three reference dates covered in this study indicates the reason for this statement. Bearing in mind that this tabulation is restricted to investor-owned systems it is not surprising to note that in 1959 hydro is a scant 10 percent of total capability, while by 1980 it has declined to approximately half of that. Furthermore, it appears that only in region VII is hydro a really substantial fraction of the total.

Twenty or thirty years ago when hydro was much more important in some sections of the country than it is today the question of primary and secondary was a serious one. Ten to fifteen years ago in the Columbia River basin interruptible hydro (which is taken to be synonymous with secondary) was such a large percentage of the total energy available that the curtailment of such interruptible as occurred in late 1951 had an important impact on industry. Through the years as the more attractive hydro locations have been developed the bulk of the growth has been carried by thermal plants. The less important hydro is in the aggregate the less chance there is for having to waste water for lack of load when the generators are not operating wide open. In other words, it becomes easier and easier to put all the available hydro into primary load. By 1970 and 1980 it is believed that with the possible exception of region VII secondary hydro will have become a matter of no concern at all.

The situation in region VII calls for special consideration, and the question of primary and secondary here has been left unanswered, but for a different reason, namely the development of so many major locations by public bodies. The question of primary and secondary under these conditions depends not on the characteristics of any single installation, but becomes a matter of dispatch for an area as a whole. It is felt, however, that on a kilowatt capability basis it would not be wrong to consider the whole installation as primary.

Production costs

An increasing number of hydro projects are being operated at low plant factor to supply the peak portion of the load curve and thus increase the productive use of thermal plants. Other hydro projects have variable seasonal outputs because of the fluctuations in streamflow. They are justified by satisfying system energy requirements during critical periods of adverse flow.

Increased consideration is being given to the application of pumped storage to convert valley thermal energy to peak requirements. Some of this pump storage capacity will be in combination with conventional hydro installations while other portions of it will be used in projects that use only the pump storage concept. Because the repetitive recirculation of water from tailrace to headwater to tailrace will result in no consumption of water, no significant impact on the water resource problem will be incurred. Even where artificial ponds are established, only the initial charge of water to fill the system plus a negligible amount of makeup for evaporation losses will be required.

Production costs of pump storage projects are not meaningful in themselves because they become involved with other system costs.

In all probability most of the future hydro capacity installed by investor-owned systems will be operated in one or more of the ways described above and thus production costs either on a capacity or energy basis are not meaningful. For these reasons production costs of future hydro capacity to be installed by investor-owned systems are not given in this report.

Water usage

There is no consumptive use of water in the actual generation of electrical energy at hydroelectric plants. As is well known, hydroplants convert the potential energy of water at a higher elevation to electrical energy by passing the water through hydraulic turbines. Thus, water is used but not consumed.

There is, however, some evaporation in the reservoirs of storage-dam hydroplants. The amount of this evaporation is difficult to calculate because of the many factors affecting the evaporation rate.[4] In humid sections of the country, while it may be difficult to calculate the evaporation rate, it is known from practical experience that the losses are of no serious consequences. In fact, the amount of water lost through evaporation in some cases is probably not as great as the transpiration loss of the trees and vegetation removed for the construction of the reservoir.

But evaporation may become substantial under arid and semiarid conditions and, therefore, must be considered in evaluating a project. For instance, according to a recent study of the application of probability analysis to water supply problems by the U.S. Department of the Interior,[5] if reservoirs with capacity beyond an additional 10 to 15 million acre-feet are constructed in the upper Colorado River Basin, evaporation loss will thereafter offset the hydrologic benefit of the regulation so achieved. It has been estimated that 11.5 million acre-feet (3,750 billion gallons) of water are evaporated annually from existing water surfaces in 11 Western States.[6]

An added difficulty in estimating future evaporation losses would be experienced if multipurpose projects are under consideration. In developments such as these the water losses must be allocated on a ratio basis to power, irrigation, flood control and navigation. To do this it becomes necessary to determine the amount of water in the reservoir and the duration and purpose of its retention therein. Because of the many variables and complexities involved, no determination of consumptive use of investor-owned hydroplants was considered feasible for the purpose of this study.

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[4] The evaporation rate depends on the reservoir's size, depth, soil conditions and elevation above sea level and the wind, temperature, and humidity conditions of the surrounding area. These latter atmospheric conditions can change daily.

[5] "Probability Analysis Applied to a Water-Supply Problem," Geological Survey Circular 410, Geological Survey, Washington 25, D.C., p. 15.

[6] Ackerman, E. A. and Lof, G. O., "Technology in American Water Development," Resources for the Future, Inc., 1959, table 7, p. 54.

V. WATER REQUIREMENTS FOR THERMAL PLANTS

Water is used in thermal plants mainly for condensing the steam. All other uses are so small as to be insignificant. Only a very small proportion of this cooling water, that portion evaporated in cooling towers or ponds, is actually a consumptive use.

In developing the estimated cooling water requirements of future thermal powerplants the analysis was broken down into the following categories:

1. Installations in which the cooling water is withdrawn from, and returned to, a natural river.
2. Installations in which cooling water is withdrawn from, and returned to, a natural lake.
3. Installations in which the cooling water is withdrawn from, partially consumed (by evaporation or windage loss) and returned to an artificial reservoir or pond constructed for cooling purposes.
4. Installations in which cooling water is partially consumed by evaporation or windage loss in cooling towers.
5. Installations in which salty or brackish cooling water is withdrawn from, and returned to, coastal waters and estuaries.

In the above cases, all of the water entering the condenser is discharged unchanged except for an increase in temperature. Regardless of the source of cooling water the quantity of water circulated is determined by a number of factors. The two most important design factors are the station thermal efficiency which determines the heat rejected to the condenser and the temperature rise from cooling water inlet to outlet. Total water circulated during actual operation is a function of the hours the generating unit is in operation rather than the kilowatt-hours generated, although in some instances throttling or shutting down one of two circulating pumps during period of low load or low source water temperatures has an influence.

In many cases, the cooling water passed through one generating station will again be passed through one or more stations located downstream on the same river. Thus, the sum of total intake by several plants on the same river leads to erroneous conclusions and in some cases leads to flow quantities much greater than the total flow of the river.

The consumptive use of water imposed by a thermal plant, not its total intake, is the important consideration. The increase of river temperature may be a factor in the overall analysis of the water resource problem. Where cooling towers are employed a quantitative determination of water consumption can be made within reasonable limits. In such cases the total rejected heat from the turbine is dissipated by evaporation of a portion of the total water circulated. It is, therefore, necessary to determine the makeup requirements and provide source and pumping quantities when the project is designed. The theory and practice is well established for this type of cooling.

Where artificial reservoirs or ponds are employed, adequate surface areas and volumes must be determined to effectively dissipate the rejected heat from the turbine. Theoretical and empirical data are available to predict the makeup or consumption of cooling water required for such installations.

In the case of withdrawal of water from rivers, several factors are introduced which make it difficult to determine the consumptive use. The relationship of the quantity of cooling water to the total volume of the stream and variations in streamflow and stream temperature are some of the factors that must be taken into consideration. However, although accurate values of use are difficult to determine, it is reasonable to assume that they will be less than those of cooling towers and, in most instances, insignificant.

Where thermal plants obtain cooling water from coastal and estuary sources, the total intake and consumptive water quantities are not involved in the problems concerned with fresh water.

Based on the above considerations the estimated water requirements of thermal plants to be installed by investor-owned systems and classified according to the various categories of cooling water employed, and by drainage areas are shown in table VII.

Table VII.—*Cooling water circulated in thermal plants, investor-owned systems, forecasted by Edison Electric Institute*

[Billions of gallons of water circulated per year]

1959

Drainage area	Rivers	Lakes	Brackish and sea water	Cooling towers	Artificial reservoirs or ponds	Total
North Atlantic	101	1	1,040	1		1,143
Upper Hudson	119					119
Lower Hudson and coastal area	5		2,352			2,357
Delaware	1,097		136	5	13	1,251
Chesapeake	526		856		20	1,402
Southeast	2,217	59	1,471	34		3,781
Tennessee-Cumberland				92		92
Ohio	5,075			114		5,189
Eastern Great Lakes-St. Lawrence	219	1,508				1,727
Western Great Lakes	169	1,072				1,241
Missouri-Hudson Bay	266	62		218		546
Upper Mississippi	1,956	75		30		2,061
Lower Mississippi	337		148	150	185	820
Arkansas-White-Red	330	257		522	57	1,166
Western Gulf		220	451	1,075	281	2,027
Colorado	5			189		194
Great Basin	5			101		106
Pacific Northwest						
South Pacific			1,366	225		1,591
Total	12,427	3,254	7,820	2,756	556	26,813

1970

Drainage area	Rivers	Lakes	Brackish and sea water	Cooling towers	Artificial reservoirs or ponds	Total
North Atlantic	440		1,643	43		2,126
Upper Hudson	488					488
Lower Hudson and coastal area			3,623			3,623
Delaware	2,135		461	33	13	2,642
Chesapeake	895		1,452	164	126	2,637
Southeast	3,890	312	4,332	76	214	8,824
Tennessee-Cumberland				141	58	199
Ohio	8,898			408		9,306
Eastern Great Lakes-St. Lawrence	224	3,200				3,424
Western Great Lakes	111	2,668		15		2,794
Missouri-Hudson Bay	734	244		528	42	1,548
Upper Mississippi	3,980	96		201	160	4,437
Lower Mississippi	1,562		308	157	148	2,175
Arkansas-White-Red	454	528		1,227	185	2,394
Western Gulf		1,120	1,838	2,112	1,230	6,300
Colorado	23			945	9	977
Great Basin	5			145		150
Pacific Northwest	3					3
South Pacific			2,798	440		3,238
Total	23,842	8,168	16,455	6,635	2,185	57,285

1980

Drainage area	Rivers	Lakes	Brackish and sea water	Cooling towers	Artificial reservoirs or ponds	Total
North Atlantic	541		2,869	16		3,426
Upper Hudson	826					826
Lower Hudson and coastal area			5,466			5,466
Delaware	2,881		1,148	30	13	4,072
Chesapeake	1,998		2,295	427	126	4,846
Southeast	7,249	1,408	6,444	1,046	497	16,644
Tennessee-Cumberland				127	89	216
Ohio	14,890	118		827		15,835
Eastern Great Lakes-St. Lawrence	607	6,169				6,776
Western Great Lakes	82	4,753		70		4,905
Missouri-Hudson Bay	1,840	244		1,229	43	3,356
Upper Mississippi	6,623	115		357	460	7,555
Lower Mississippi	3,751		686	158	133	4,728
Arkansas-White-Red	897	981		2,734	783	5,395
Western Gulf		1,472	3,672	5,153	2,740	13,037
Colorado	199			2,319	9	2,527
Great Basin	5			508		513
Pacific Northwest	366					366
South Pacific			5,435	485		5,920
Total	42,755	15,260	28,015	15,486	4,893	106,409

The same estimated water requirements of thermal plants to be installed by investor-owned systems but classified according to FPC regions are shown in table VIII.

Table VIII.—*Cooling water circulated in thermal plants, investor-owned systems, forecasted by Edison Electric Institute*

[Billions of gallons of water circulated per year]

1959

Regions	Rivers	Lakes	Brackish and sea water	Cooling towers	Artificial reservoirs or ponds	Total
I	2,002	322	4,258	6	33	6,621
II	4,953	1,460		176		6,589
III	2,308	59	1,597	34		3,998
IV	2,404	920		104		3,428
V	635	477	599	1,811	523	4,045
VI	120	16		111		247
VI	5			101		106
VIII			1,366	413		1,779
Total	12,427	3,254	7,820	2,756	556	[1] 26,813

1970

Regions	Rivers	Lakes	Brackish and sea water	Cooling towers	Artificial reservoirs or ponds	Total
I	4,179	578	6,951	370	33	12,111
II	8,701	3,761		403		12,865
III	4,019	312	4,560	76	378	9,345
IV	4,606	1,762		288	160	6,816
V	2,067	1,620	2,146	3,694	1,563	11,090
VI	242	135		274	51	702
VII	28			211		239
VIII			2,798	1,319		4,117
Total	23,842	8,168	16,455	6,635	2,185	[1] 57,285

1980

Regions	Rivers	Lakes	Brackish and sea water	Cooling towers	Artificial reservoirs or ponds	Total
I	6,659	1,218	11,466	604	33	19,980
II	14,206	7,378		786		22,370
III	7,976	1,408	6,756	1,128	692	17,960
IV	8,053	2,696		433	460	11,642
V	4,888	2,384	4,358	8,586	3,657	23,873
VI	406	176		861	51	1,494
VII	391			574		965
VIII	176		5,435	2,514		8,125
Total	42,755	15,260	28,015	15,486	4,893	[1] 106,409

[1] Eliminating withdrawals from the Great Lakes and coastal waters from gross water intake the estimated consumptive use from all other sources is approximately 123,000,000,000 gallons in 1959; approximately 262,000,000,000 gallons in 1970; and approximately 506,000,000,000 gallons in 1980.

It can be noted from an inspection of table VIII that in 1970 a total of 57,285 billion gallons of cooling water will be pumped through thermal plants and returned to its source. By 1980, this amount will have increased to 106,409 billion gallons of water. A comparative figure for 1959 is 26,813 billion gallons.

As previously outlined, these large quantities of water represent the total volume of water circulated (and recirculated) through the steam condensing system of thermal plants and do not indicate consumptive use of water any more than the volume of water through the radiator of an automobile engine indicates the amount of water that needs to be added to the radiator.

The total water passed through thermal plant condensers in 1959 is somewhat lower than would be expected under normal operating conditions. Loads were lower than estimated due to the industrial recession, the impact of the steel strike in the industrialized regions, and unusually cool weather in other regions. New generating capacity was still being installed according to previously established schedules so that more than adequate capability was available. This resulted in large capability margins and thus older and less efficient units were not operated. Furthermore, in estimating the circulating water requirements of future nuclear powerplants it was felt that such plants would not have the same efficiencies as comparable conventional plants. These conditions should be taken into consideration in making comparisons with water circulation requirements of future years.

Coastal waters will continue to be the source of a relatively large amount of cooling water. Of the above total amounts, it is estimated that 16,455 billion gallons of cooling water will be obtained from coastal waters in 1970, and 28,015 billion gallons of water in 1980. The source of supply of such coastal waters can be eliminated from any analysis of our future fresh water needs because no fresh water is involved, only salt water that is being circulated.

The thermal plant cooling water withdrawn from, and returned to, the Great Lakes is estimated at 5,868 billion gallons for 1970 and about 10,922 billion gallons for 1980. These amounts can also be eliminated from any overall national studies because the consumptive uses represented by these intake quantities will be insignificant compared to the natural evaporation of these large bodies of water. A similar line of reasoning could be proposed for other large lakes used for thermal plant cooling purposes, although no attempt has been made in this study to do so.

The annual cooling water withdrawn from, and returned to, rivers alone in individual regions and for the United States as a whole can readily be compared to total withdrawals from all sources for 1959, 1970, and 1980 by inspection of table VIII. For the total United States the cooling water withdrawn from rivers expressed as a percentage of total withdrawals for cooling purposes is 46 percent in 1959, 42 percent in 1970 and 40 percent in 1980.

Considering total withdrawal, exclusive of those from coastal waters and the Great Lakes, the quantity of water from all other sources estimated for 1959 is 16,413 billion gallons. Even if the consumptive use of plants from these other sources was as high as three-fourths of 1 percent the quantity of water consumed would only be 123 billion gallons, or only 3.3 percent of the natural evaporation from the water surfaces of the 11 Western States referred to in section IV. Projecting to 1980 estimated consumptive use from the same water sources by investor-owned thermal plants is 506 billion gallons and only 13.5 percent of the present natural evaporation from the water surfaces in the 11 Western States.

The electric industry realizes the importance of conserving cooling water. Requirements per kilowatt of installed capacity have been materially lowered by utilization of larger units operating at higher temperatures and pressures. This trend will continue and is reflected in the estimated quantities submitted in this report.

In 1940 turbine generator units of 35 to 40 megawatt capacity designed for steam conditions of 850 p.s.i.g., 900° F. were quite commonplace. Such turbines rejected about 5,600 B.t.u. per kw-hr. to the cooling water.

In 1950, 100 megawatt turbines designed for 1,450 p.s.i.g., 1,000/1,000° F. were typical. They rejected about 4,600 B.t.u./kw-hr. to the cooling water.

Some units recently installed, impose a rejection to the cooling water of only 3,480 B.t.u./kw-hr. which is only 63 percent of the 1940 average.

GLOSSARY OF TERMS

Acre-foot A volume of water sufficient to cover an area of 1 acre to a depth of 1 foot.

Adverse water conditions: Water conditions limiting the production of hydroelectric power either from low water supply or reduced gross head.

B.t.u. (British thermal unit): The standard unit for measuring quantity of heat energy, such as the heat content of fuel. It is the amount of heat energy necessary to raise the temperature of 1 pound of water 1 degree Fahrenheit.

Cooling towers: When natural supplies of condensing water are insufficient, cooling towers are employed to cool the water for recirculation through the condenser. The purpose of a cooling tower is to bring the partially saturated air and the warm condensing water into intimate contact so that the air will be warmed and will absorb more water by evaporation, thus raising its relative humidity and cooling the condensing water.

Electric energy: As commonly used in the electric industry, electric energy means kilowatt-hours.

Energy cost: It is the cost of producing electric energy at a generating station and is usually expressed in mills per kilowatt-hour. As used herein it includes an appropriate charge for the capital equipment in the plant (all equipment up to and including the high-voltage side of the step-up transformer for the purposes of this report), operation and maintenance expenses, and the cost of fuel.

Gross margin: Difference between capability and peak load.

Head: The head on a hydroelectric plant is the pressure resulting from the difference between the elevation of water at the intake and the elevation of tailwater level, at the discharge from the powerplant.

Heat rate: A measure of thermal generating station efficiency generally expressed in B.t.u. per net kilowatt-hour. It is computed by dividing the total B.t.u. content of fuel burned for electric generation by the resulting net kilowatt-hour generation.

High density load areas: Areas where there is a concentration of many large size loads.

Hydro system: System that utilizes hydropower as its main source of supply for electric energy.

Kilowatt: 1,000 watts.

Kilowatt-hour: Basic unit of electric energy equal to 1 kilowatt of power supplied to or taken from an electric circuit steadily for 1 hour.

Load center: Point at which the load of a given area is assumed to be concentrated.

Maintenance expense: Includes labor, materials, overhead, and other expenses incurred in preserving the operating efficiency or physical condition of utility plant.

Median hydro conditions: The rate of discharge for which there are equal numbers of greater and lesser flow occurrences during a specified period.

Megawatt: 1,000 kilowatts.

M kilowatt-hours: A million kilowatt-hours.

Net capability: The maximum load which the station can carry with all equipment available, and no allowance for outages, for some short period of time, usually not over 4 hours. Station use is not considered a part of this maximum load.

Net kilowatt hour: Gross generation less plant use.

Operating expense: Includes labor, materials, overhead and other expenses (except maintenance) incurred in operation of utility plant.

Peakload: Maximum load encountered on the system during a given period of time.

Peak portion of the load curve: The uppermost portion of the area included under a curve developed by plotting load (usually in kilowatts) against time (usually in hours) for a specific period.

Primary hydropower: Maximum potential power constantly available for transformation into electric power.

Pumped storage plants: Hydroplants that pump all or a portion of their own water supply. Essentially they consist of a tailwater pond, which may be replaced by a river or a natural lake, and a headwater pond. During times of peakload, water is drawn from the headwater pond to operate hydroelectric generating units over the peak of the load curve. During the off-peak hours, pumps are operated to lift the water back from the tailwater pond to the headwater pond. Power for operating the pumps is furnished by offpeak steam generated energy, sometimes supplemented by secondary hydroenergy.

Regional capability: As reported herein, it is the sum of the capabilities of the systems serving the region. The capability for the country as a whole is reported as the sum of the capabilities of the eight power supply regions.

Regional peakloads: As reported herein they are the sum of the peakloads on the systems serving the region, account being taken of any diversity between peaks on systems that are operated as a closely coordinated group.

Secondary hydropower: All hydroelectric energy other than primary hydropower.

Self-generation: Generation of energy by an industrial plant for its own use.

Steam condensing system: Power station equipment involved in cooling turbine exhaust steam, thereby reconverting it into water.

Step-up transformer: As used herein a transformer that increases the voltage from that of the generators to that desired for transmission.

Tailrace: Channel through which the water flows after passing through a hydraulic turbine.

Valley thermal energy: Electric energy (produced from heat sources) represented by the area under the load curve over sections of the curve lying between relative load peaks.

Watt: The electrical unit of power or rate of doing work. It is the rate of energy transfer equivalent to 1 ampere flowing under the pressure of 1 volt at unity power factor; 1 horsepower equals 746 watts.

REPORT OF THE AMERICAN PUBLIC POWER ASSOCIATION ON THE FUTURE OF THE ELECTRIC POWER INDUSTRY IN RELATION TO WATER RESOURCES

AMERICAN PUBLIC POWER ASSOCIATION,
Washington, D.C., December 4, 1959.

Senator ROBERT S. KERR,
Chairman, Select Committee on National Water Resources,
U.S. Senate, Washington, D.C.

DEAR SENATOR KERR: Enclosed please find 25 copies of our memorandum in response to your letter of June 23, 1959, requesting information which may be of help to the select committee in its studies.

We hope that this report will be of service to the committee in its important task. Please do not hesitate to ask for additional copies.

Sincerely,

ALEX RADIN, *General Manager.*

MEMORANDUM

To: The Select Committee on National Water Resources, U.S. Senate.
From: The American Public Power Association.

This memorandum is in response to a letter of June 23, 1959, from the Senate Select Committee on National Water Resources requesting information on resources as they relate to future trends in electric power requirements and production.

Specifically, the committee requested information on the following:

1. Electric energy demands and capacity requirements by region, at present and projected to 1970 and 1980, with a breakdown to show the extent to which demands are met and anticipated to be met by hydro, thermal, or other sources, including nuclear energy.
2. Estimates of per capita electric energy demands for the United States for the present and in 1970, 1980, and 2000, in the following categories:
   (a) Household and farm.
   (b) Industrial and commercial.
   (c) All other.
3. Recommended means of adding capacity, 1970 and 1980, by region, with costs of production for each broken down to the extent possible into capital charges, fuel, maintenance, etc., and with information as to water requirements.
4. Estimated amounts of primary and secondary hydropower that can be developed in 1970 and 1980, by regions, assuming capacity increments as in 3 above.
5. General comments by the American Public Power Association on trends in the production of electric energy, on the power requirements of the Nation, and means by which they can best be met, on water requirements for hydropower and for cooling, and on other matters which the American Public Power Association believes may be of value to the committee in its consideration of the Nation's water problems.

These data are of course essential to intelligent water resource planning and development. However, this association is not equipped to undertake the comprehensive investigations required to develop the information requested in questions 1 through 4.

While such information is essential, it is of only limited value if the forward projections involved are based upon inadequate assumptions. If the basic assumptions are inadequate, the resulting forecasts of future power requirements also are likely to be inadequate, leading in turn to inadequacies in the planning of water resources development.

The association, therefore, has attempted, in this memorandum, to point up what appear to have been fundamental weaknesses in earlier power requirements forecasting, to demonstrate that these weaknesses seem to have been endemic, and to make the case for greater boldness in estimating future power and water requirements.

INTRODUCTION

Forecasts of future electric power requirements in the United States characteristically have underestimated the rate of growth of power consumption. The consistent conservatism of expert forecasts has been astonishing. This conservatism not only has characterized the gross forecasts of total national consumption but has cropped up in considerations of individual power development schemes.

Every new forecast of national needs has shown that earlier forecasts, some only a few years old, were too conservative. The forecasts reflect, in some measure, the conservatism of the private utility experts who, in the early thirties, maintained that there would be "no conceivable market" for power from the proposed Tennessee Valley

Authority dams. The only customers for Grand Coulee power, the country was warned, would be the jackrabbits.

A like attitude of "no urgency" is currently expressed in respect to the development of low-cost nuclear power.

Overly conservative forecasts have more than academic meaning. They can affect adversely national policies on water and energy resource development. To the extent that water resource planning is based upon unrealistically low estimates of future power use, it will fall short of meeting the needs of the American people.

The habitual conservatism in forecasts is in part a reflection of an attitude within much of the power industry which inhibits the adoption of progressive rate and sales philosophies, militates against imaginative water resource programs, and prevents a truly aggressive attack on the development of low-cost nuclear power.

Hydroelectric programs may be uniquely susceptible to error in projecting future needs. National hydroelectric power potentials are generally viewed as limited by a maximum number of feasible sites. Yet the number of feasible sites has increased as technological advances periodically have occurred, and the estimates of the total potential hydropower capacity of the United States accordingly have risen regularly. In 1935, for instance, the Federal Government estimated total U.S. economic hydropower potential at less than half of today's estimate, which doubtless also is too low.

One consequence of conservative attitudes toward future hydro development is an unwarranted skepticism of individual multiple-purpose projects proposed as elements in water resources planning. Adequate future development will require a flexibility of approach that permits constant reassessment of feasibility, with the recognition that what is impossible now may become, at a later date, both feasible and desirable.

In general, a conservative philosophy within the electric power industry toward its own future means a less rapid rise in general living standards and a less vigorous rate of industrial development than otherwise could be attained. A recent comprehensive study of national water resource development by Ackerman and Lof points out that "plentiful and cheap electric power is a strong aid to industrial activity in any area." [1]

The remainder of this paper will seek to demonstrate these general points; namely, that—

(1) forecasts of future power needs have been characteristically low;

(2) estimates of the Nation's potential economic hydropower capacity have been characteristically low;

(3) the market for electricity is highly elastic and responsive to rates, and unit costs are inversely related to sales volume. Greater sales bring lower unit costs which permit lower rates and bring greater sales.

FORECAST OF FUTURE POWER REQUIREMENTS

A complete census of past predictions of future electric power requirements has not been attempted. Principal attention has been given to the estimates of the Federal Power Commission, since these are the only periodic "official" forecasts, with occasional reference to those of a leading trade journal, Electrical World. In both cases, there has been a continuing tendency to underestimate the Nation's future power requirements, with FPC being the worst offender.

A January 5, 1935, editorial in Electrical World magazine is of interest in this connection. It said that the chief need was for "generating power in comparatively small stations at the loads and load centers * * *" and that—

> Added generating capacity is in the offing. Unfortunately, many utility executives and Federal authorities have the false conception that the economies of power supply favor the use of very large stations and long transmission lines. * * * The economic distance for electric power transmission lines decreased steadily in recent years and is now in the order of 60 miles instead of the hundreds of miles so often publicized.

The experience of the succeeding 24 years, of course, has completely vindicated the conceptions of the "utility executives and Federal authorities" of which the editor was so scornful.

Also, in 1935, the Federal Power Commission published its "National Power Survey—Interim Report." In an attempt to give the country meaningful data, the Commission made inquiries of the Nation's private utilities in order to predict electric power capacity and generation to meet the "resumption of predepression industrial activity." (Up to then, Government data on electricity production had been handled largely by the Geological Survey.)

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[1] Edward A. Ackerman and George O. G. Lof, "Technology in American Water Development," Johns Hopkins Press, 1959, p. 318.

The FPC recorded electric power consumption as having fallen from 71.4 billion kilowatt-hours in 1929 to 63 billion kilowatt-hours in 1933, based on reports from power systems supplying 93 percent of the Nation's total needs. The Commission then estimated that an additional 20 percent of the 1929 consumption would be needed upon "resumption of predepression industrial activity," for a total exceeding 85 billion kilowatt-hours. A rough estimate of the Nation's hydroelectric power potential also was made, with an indicated possible total installed capacity of 52,628,900 kilowatt-hours.[2]

The validity of the first figure would depend in large part on just when "predepression industrial activity" could be considered achieved. The same year, 1935, for instance, experienced a national electricity generation of the electric utility industry of more than 95 billion kilowatt-hours, and 1940 experienced a total of 141.8 billion kilowatt-hours. In terms of consumption (somewhat less than generation due to transmission and other losses) it appears that the desired 20 percent increment had been attained or surpassed at the time of publication of the 1935 estimate.

The estimate of hydro potential was more specific, and clearly too pessimistic. It was much less than half the potential currently estimated for the United States by the FPC.

Prewar estimates

Mobilization for World War II became a great concern of the Commission and in one of its statements the FPC was highly critical of the 1940 load forecasts made by private power systems. In the first of what was hoped would become a series of estimates of anticipated growth of electric loads, the Commission commented on forecast reliability. Among the conclusions:

> The demand for power is growing more rapidly than the utility systems expected. Their December 1940 demand of 27,752,856 kilowatts exceeded their September 1940 demand by 2,609,154 kilowatts. This increase exceeded by 472,440 kilowatts, or 22 percent, the estimates in the September report of the utilities.[3]

The FPC then pointed out that nine "important war material areas underestimated needs by 53 percent; in some areas, increases were approximately double those anticipated." Such miscalculations, the Commission cautioned, "would mean serious power shortages such as threatened the defense effort in 1918."

The intended series of forecasts did not materialize, unfortunately, but subsequent reports and estimates do not indicate exclusive reliance on load forecasts of private power systems which earlier had proved so inadequate.

The FPC itself has acknowledged the tendency of most long-term projections to prove to be too low. "Of the numerous long-range estimates made by various authorities just prior to the Korean war," the Commission pointed out in 1955, "one was far above the others, predicting that the Nation's electric utility energy requirements would reach 657 billion kilowatt-hours in 1960," a figure the FPC then correctly said would probably be surpassed by 100 to 150 billion kilowatt-hours.[4]

This tendency to underestimate reappeared during the Korean conflict. In its 1952 report on "Resources for Freedom," the capable President's Materials Policy Commission predicted a total (utility and nonutility) 1975 production of 1.4 trillion kilowatt-hours. This figure now is clearly low compared with other more recent estimates.

FPC predictions

The Commission has assigned a large share of the credit for unexpected capacity additions to war and defense measures. Yet recent years have witnessed periodic Commission increases in its own projections made 1, 2, or 3 years earlier. Chart A shows four of the projections made by FPC since the Korean war, illustrating the inherent conservatism of the Commission's forecasting of power needs.

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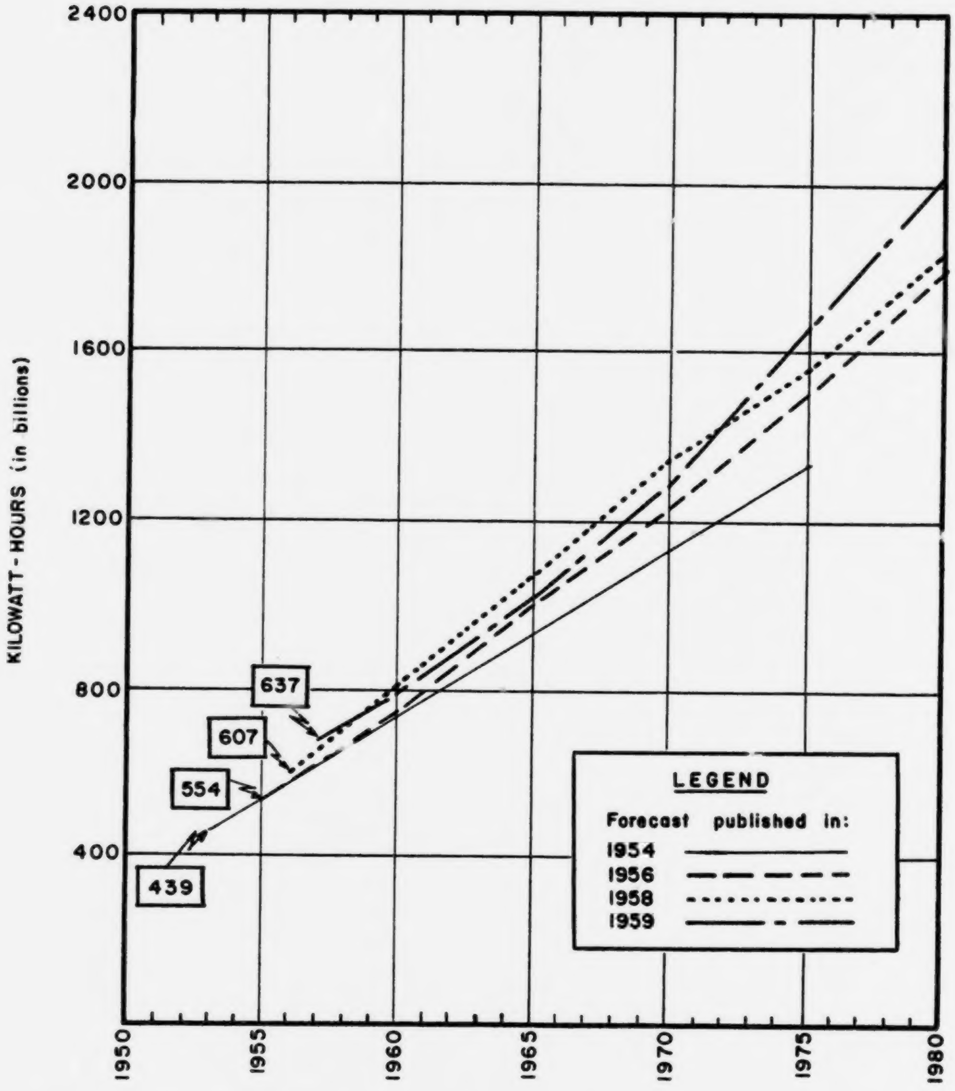
[2] Federal Power Commission, "National Power Survey—Interim Report, Power Series No. 1," Government Printing Office, 1935, table 14, p. 33.

[3] Federal Power Commission, "Electric Power Requirements and Supply in the United States," 1940, p. 1.

[4] Federal Power Commission, "Estimated Future Power Requirements of the United States by Regions—1955-80," 1956, p. 4.

CHART A

FEDERAL POWER COMMISSION
FORECASTS OF FUTURE U.S. POWER NEEDS



Source: FPC, "Estimated Future Power Requirements: 1953-1975" June, 1954; "Estimated Future Power Requirements: 1955-1980" December, 1956; "Electric Power Requirements and Supply of the United States" April, 1958; Press Release No. 10,480, June 17, 1959.

The chart compares the FPC's forward estimates published in 1954, 1956, 1958, and 1959. Each shows the preceding one to have undershot. Its 1959 forecast for 1975, for example, is more than 300 billion kilowatt-hours greater than that predicted 4 years earlier. This represents about a 23-percent error in judgment.

At least some of the FPC regional forecasts have been no better. In its December 1944 "Southwestern Region Power Market Survey," for example, the FPC regional office estimated future annual energy demands of 12 billion kilowatt-hours by 1950, 15 billion kilowatt-hours by 1955, 18 billion kilowatt-hours by 1960, and 21 billion kilowatt-hours by 1965.

For essentially the same service area, however, actual production approximated 18 billion kilowatt-hours in 1947, according to its survey of June 1950. (The latter survey also predicted a 1955 total of 29 billion kilowatt-hours, 36 billion kilowatt-hours for 1960 and over 49 billion kilowatt-hours for 1970.) Thus, actual power consumption in the region during a largely "peacetime" period exceeded 6-year predictions by 50 percent in only 3 years.

Similarly, power surveys of power service area No. 30 (most of Montana) display a wide gap between official prediction and reality. The 1949 "Power Market Survey, Missouri River Basin, Area A" of FPC predicted that area 30 production would be about 2.3 billion kilowatt-hours for 1950, 3.2 billion kilowatt-hours for 1960, and 3.9 billion kilowatt-hours for 1970. By 1954, however, area 30 reported a generation of 3.2 billion kilowatt-hours in FPC's reports, the same figure postulated for 1960 only 5 years earlier. The Commission's 1954 projections for area 30, furthermore, predicted a generation of 7 billion kilowatt-hours by 1965.

On the national level, FPC predictions published in 1959 postulate a 33.3 percent increase from 1960 to 1965, 26.9 percent from 1965 to 1970, 23.3 percent from 1970 to 1975, and 20.6 percent from 1975 to 1980. The major elements of this prediction were repeated only recently in FPC testimony at the October 1959 hearings of the Subcommittee on Automation and Energy Resources of the Joint Economic Committee.

At this hearing, the FPC spokesman again acknowledged that its projections were noticeably more conservative than some by the industry itself. And the Chief of FPC's Bureau of Power noted one reason for the conservatism:

> The forecasts of the electric power industry appear to be in the nature of goals that the industry feels may be reached through intensive sales efforts. Sales goals are often higher than actual accomplishments, although in the case of electric power, actual loads have generally been higher than the estimates of the Federal Power Commission as well as those of other parties.

Other projections

Two comparative estimates are noted on chart B, along with an FPC projection. One is derived from the forecast of September 1959 by Electrical World, a trade journal which in recent years has undertaken to predict future power use. The second portrays a 6.5-percent annual rate of growth of electricity generation. The figure was used by the Congressional Joint Committee on Atomic Energy's Panel on the Impact of the Peaceful Uses of Atomic Energy in its 1956 report. This Panel in forecasting power needs used a "low" (4 percent compounded annual growth) and a "high" (6.5 percent) estimate.

The predicted annual rate of growth in Electrical World's estimate approximates 8 percent, with a resulting utility generation of 2.4 trillion kilowatt-hours by 1975. (The 1980 figure on the chart has been extrapolated for purposes of comparison and is not the magazine's estimate.)

The 6.5 percent rate curve estimates about 2 trillion kilowatt-hours by 1975 and about 2.7 trillion kilowatt-hours by 1980. A parallel projection is that made by a leading private utility engineer, Philip Sporn, president of the American Electric Power Co., at the recent Joint Economic Committee subcommittee hearings. Mr. Sporn there estimated utility generation at about 2,000 billion kilowatt-hours by 1975, the same figure he had predicted for 1975, 4 years earlier.[5]

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[5] Statement before the Subcommittee on Automation and Energy Resources, Joint Economic Committee, Oct. 13, 1959. And Philip Sporn, "The Role of Energy and the Role of Nuclear Energy in the United States," "Peaceful Uses of Atomic Energy"; "Proceedings of the International Conference in Geneva," 1955, vol. 1, p. 423.

CHART B

FUTURE ELECTRIC UTILITY GENERATION
FOUR PROJECTIONS

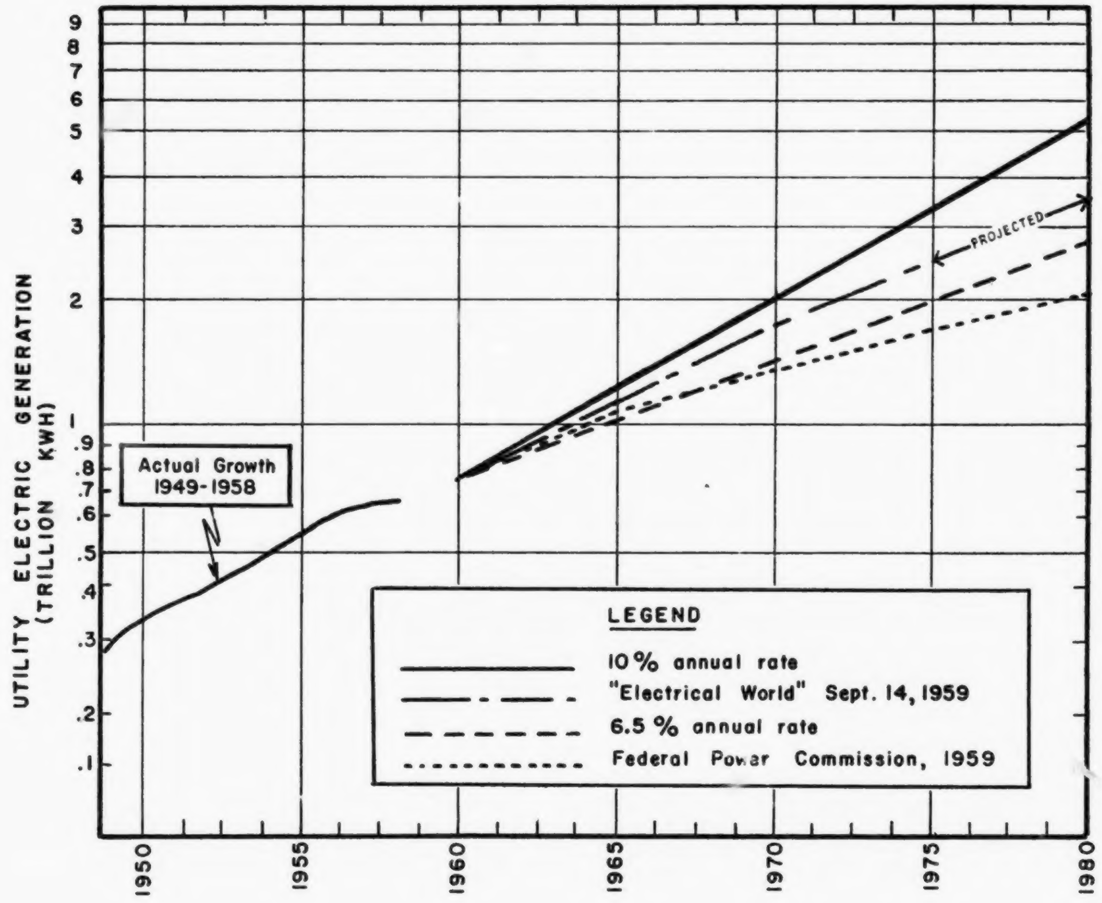

TABLE 1.—*Electricity generation in the United States: 1902–58 (utility and industrial)*

[In billions of kilowatt-hours]

Year	*Generation*	*Year*	*Generation*
1902	6. 0	1937	146. 5
1907	14. 1	1940	179. 9
1912	24. 8	1942	233. 1
1917	43. 4	1945	271. 3
1922	61. 2	1947	307. 4
1925	84. 7	1950	388. 7
1927	101. 4	1952	463. 0
1930	114. 6	1955	629. 0
1932	99. 4	1957	716. 4
1935	118. 9	1958	[1] 725. 9

[1] Assuming nonutility generation equal to that of 1957.

Source: Federal Power Commission reports; see also Bureau of the Census, Historical Statistics, series G171–190, p. 156.

In terms of capacity requirements, measured in kilowatts, Electrical World suggests a 1975 figure of 479 million kilowatts; the 6.5 percent annual rate would mean 438.4 million kilowatts; and the FPC predicts 376.2 million kilowatts by that date.

Past growth

Chart C outlines the magnitude of the growth in power generation in the United States since 1902. It includes production by both privately owned and publicly owned utilities, together with the relatively slight industrial production. Table 1 is included to show the numerical equivalents of the two growth curves for certain years.

The top, rectilinear graph shows actual quantities consumed while the bottom, logarithmic graph shows the historical rate of growth of electric generation from 1902 to 1958. Each curve's ascent is interrupted sharply by the ravages of the depression, and the slope of the growth rate, lower chart, is strikingly similar for predepression and postdepression periods.

Since 1935, the United States has recorded more than a sixfold increase in electricity production, more than doubling every 10 years. Since 1952, new capacity additions have averaged more than 10 million kilowatts each year. Since World War II, growth in total capability and generation has increased at about a 10-percent rate, compounded annually.

Chart D compares the curve of utility generation of electricity with the curve of gross national product. Developed by Mr. Sporn for the 1959 hearings of the Subcommittee on Automation and Energy Resources, these curves illustrate the apparent close relationship between GNP and power generation up to 1945. But the years that follow indicate that the relationship is more apparent than real. The continuing, brisk ascent of the power curve contrasts markedly with the falling growth rate of the gross national product index.

This phenomenon of a steady growth in the electric utility industry, not anchored to a considerably weaker curve of national economic growth, may suggest one reason for past FPC underestimates of future electric production. For the Commission may still assume, as it did in its 1954 projections, that "obviously, however, no segment of the economy can continue indefinitely to grow at a faster rate than the total economy." [6]

As a matter of fact, a direct relationship between energy consumption and GNP is not "obvious" and has been denied in testimony before the Joint Economic Committee subcommittee in October 1959. Mr. Sam H. Schurr, of Resources for the Future, Inc., concluded that "Total energy consumption cannot be related in a straightforward way to other broad economic factors such as GNP and population."

He stated that a major study by his organization pointed to a national consumption of electricity of almost 2 trillion kilowatt-hours by 1975, representing about a 210-percent increase over 1955. This figure contrasted sharply with FPC testimony at the same hearings that annual utility output will pass "2 trillion kilowatt-hours by 1980."

Innovation and electricity

This rapid and constant climb of national electricity production and consumption results from many factors. Edward S. Mason, dean of the Graduate School of Public Administration, Harvard University, has concluded that (italic supplied):

> Increased consumption of electric power seems in a variety of ways to be more intimately bound up with economic development than increase in mineral fuel intake. It seems to a greater degree to relate to new products, new producing equipment, and new sources of materials, for example, the electroprocess industries; *it seems more closely tied to the whole process of innovation.* The divisibility and easy control of electricity in very small amounts, furthermore, make it peculiarly well suited for appliances and other improved technology within the home, as handmaiden and handyman; and thereby it is heavily responsible for the liberation for other economic activity of housewives and for the almost complete disappearance (in the United States) of household servants.[7]

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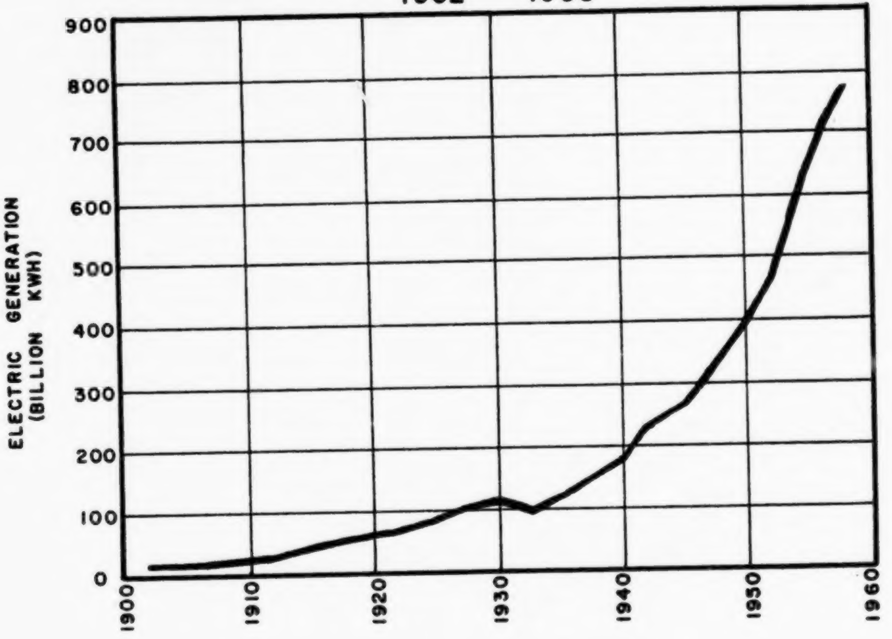
[6] Federal Power Commission, "Estimated Future Power Requirements: 1953–75," 1954, p. 5.

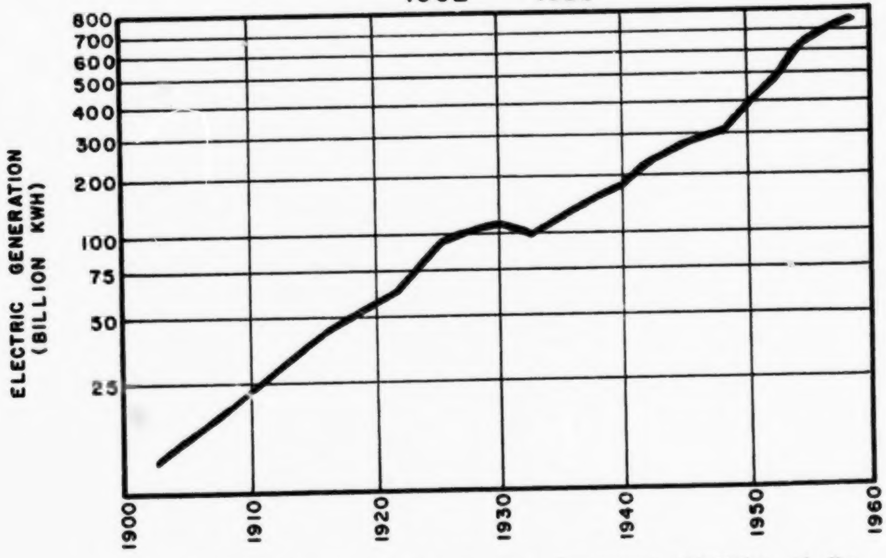
[7] Edward S. Mason, Productive Uses of Nuclear Energy, "Energy Requiremnts and Economic Growth, National Planning Association, 1955, p. 31.

CHART C

GENERATION OF ELECTRICITY IN THE UNITED STATES
1902 — 1958



RATE OF INCREASE
GENERATION OF ELECTRICITY IN THE UNITED STATES
1902 — 1958

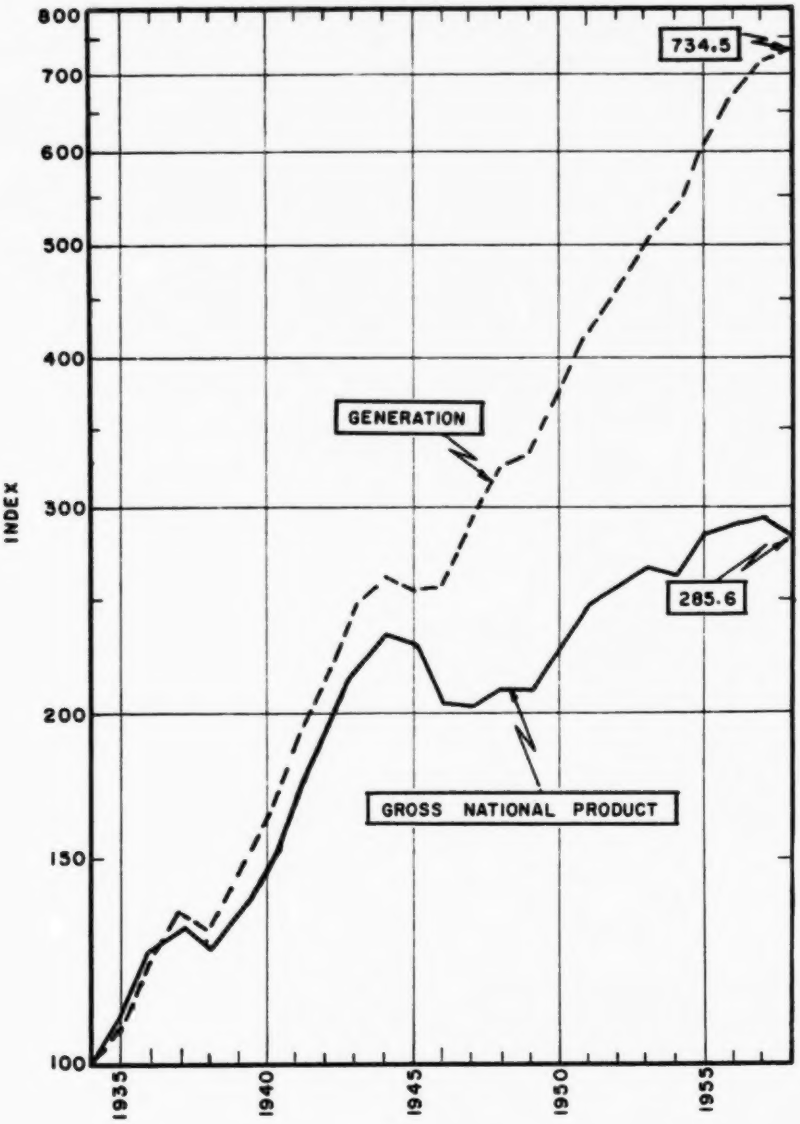


Source: Bureau of the Census, "Historical Statistics of the United States, 1789-1945" p.156, G-171-182. Federal Power Commission annual reports.

CHART D

INDEXES OF TOTAL ELECTRIC UTILITY GENERATION AND GROSS NATIONAL PRODUCT IN CONSTANT 1958 DOLLARS, 1934-1958

(1934= 100)



Philip Sporn, American Electric Power Company, October, 1959.

Whatever the reason, electricity's share of total energy consumption has become increasingly large.

Consumption of all energy (coal, oil and natural gas liquids, natural gas, water power), is "about 13 percent less" now than it was in 1900 for the Nation, Dr. Schurr has testified, in terms of energy per unit of gross national product. This index has experienced "persistent decline" since 1920.

By contrast, consumption of electricity, as noted earlier, has increased at a rate exceeding the growth rate of gross national product. The rate of growth in the use of electricity will continue to outpace growth rates for other forms of energy between 1955 and 1975, Dr. Schurr said. Elaborating, he estimated that electricity will have 210-percent increase in that period, compared to about 100 percent for natural gas, 95 percent for oil and gas liquids, 75 percent for bituminous coal, and a decline of about 30 percent for anthracite coal.[8]

High future growth rate likely

Considering our past experience, it would seem reasonable to project an annual average growth rate for electricity generation of about 10 percent, the rate computed for utilities from 1946 (223 billion kilowatt-hours) to 1958 (645 billion kilowatt-hours).[9]

The projected curve reflecting this growth rate is shown in chart B, together with the three prediction curves already described. At this rate of future growth, a total utility generation of about 3.2 trillion kilowatt-hours is projected for 1975, and more than 5.2 trillion kilowatt-hours for 1980.

By comparison, the 1959 forecast of the Federal Power Commission predicts somewhat less than one-half this 1980 figure—2 trillion kilowatt-hours versus 5.2 trillion kilowatt-hours.

The loads forecast by Electrical World for 1972–73 equal those estimated by the FPC for 1980. The 10-percent annual growth curve passes the FPC 1980 prediction 5 years earlier than that. Of the projections and predictions noted on chart D, all but the FPC projection envision at least a tripling of electrical energy production by utilities by 1980.

It is interesting in this connection to read that the Edison Electric Institute, in its latest 1959 semiannual Electric Power Survey, reports that both generating capacity and electricity production for 1959 will exceed that of 1958 by 10.3 percent.

Problems of low estimates

There could be less concern with the FPC forecasts if it were not for the fact that Commission conclusions influence the planning of both private and public organizations.

For example, the Department of Commerce this year published a study of capital investments needed for water resources by 1975.[10] Its bibliography indicated reliance upon FPC predictions, and upon other studies which utilized the FPC figures. Its conclusions are therefore subject to serious question, and its usefulness may be severely limited.

Another example is furnished by the testimony of the nuclear technology expert, Dr. Walter Zinn, in the previously mentioned October 1959 hearings of the Automation and Energy Resources Subcommittee of the Joint Economic Committee. Dr. Zinn referred to the possibility that nuclear power production by 1980 would amount to 20 percent of total electrical generation, but described this as an optimistic assumption. He applied his percentage prediction to an FPC forecast made in 1955 to derive a prediction of 360 billion kilowatt-hours of nuclear power production in 1980.

Yet, the FPC forecast upon which Dr. Zinn relied is so conservative that it is doubtful that the 360 billion kilowatt-hours is particularly "optimistic". Using other, and probably more accurate forecasts as a base, such as the recent estimates of Electrical World, one need only to assume a 10-percent share for nuclear power—half of the Zinn assumption—to derive an estimate of 350 billion kilowatt-hours, approximately Dr. Zinn's figure.

The influence of predictions by Government agencies was reflected also in the study of "Nuclear Energy and the U.S. Fuel Economy, 1955–80," published in 1958. In it, the author, Perry D. Teitelbaum, used the FPC's 1955 predictions of residential consumption of electricity which were far below those of Electrical World of the same year.

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[8] Sam H. Schurr, Director of Energy and Mineral Resources Program, Resources for the Future, Inc., before the Subcommittee on Automation and Energy Resources, Joint Economic Committee, Oct. 12, 1959.

[9] 1946 and 1958 figures from Edison Electric Institute, "Electric Utility Industry Statistics for the Year 1958," table 9, p. 4.

[10] "Water Resources Development—Capital Investment Values—1900–75," by Walter L. Picton, Director, Water and Sewerage Industry and Utilities Division, Business and Defense Services Administration, U.S. Department of Commerce.

The author also used modifications of the predictions made by the President's Materials Policy Commission for commercial consumption, which assumed a lower figure for 1975 than the Electrical World predicted for 1970. His resultant overall estimate reflected an annual growth rate of 4.3 percent for the period 1955 to 1980, lower by at least 15 percent than any of the other contemporary predictions noted in his study. It seems reasonable to assume that his apparent conservatism was encouraged by the pessimistic predictions of FPC and PMPC.

In short, there is a real need for the development by the Federal Power Commission of standards and procedures which will produce more nearly accurate power use forecasts. To be realistic, such standards must be freed of criteria and attitudes which have produced such low estimates in the past.

EXPERIENCE OF TWO REGIONS

The experience of distributors of power in the Tennessee Valley and in the service area of the Bonneville Power Administration more than supports the suggestion that the future annual rate of growth of electricity generation in the United States will approximate that recorded from 1946 to 1958—about 10 percent.

Chart E outlines the rates of growth of electricity consumption by customers of the distributors of the wholesale power supplied by TVA and BPA. TVA figures include only that power distributed by municipalities and rural electric cooperatives. The huge power requirements of the Atomic Energy Commission and other Federal agencies and some direct industrial customers have been excluded. Had these been included, the TVA curve would slope upward even more sharply.

BPA sales to Federal agencies account for less than 10 percent of the total sales, however, and an adjustment similar to that made for the TVA curve was not made. Its growth curve approximates that of TVA quite closely. That of the private power companies shows a constant, but significantly weaker, growth rate. It encompasses all sales, including those made to Federal agencies.

The achievements of the municipal utilities and rural electric cooperatives in these two regions are instructive: by 1958, the total sales of the distribution utilities served by TVA power had increased to 5.8 times the level of sales in 1945; in the case of BPA, 1958 sales were 3.3 times the agency's 1945 figure. In contrast, the private power companies' generation was only 2.66 times their 1945 figure.

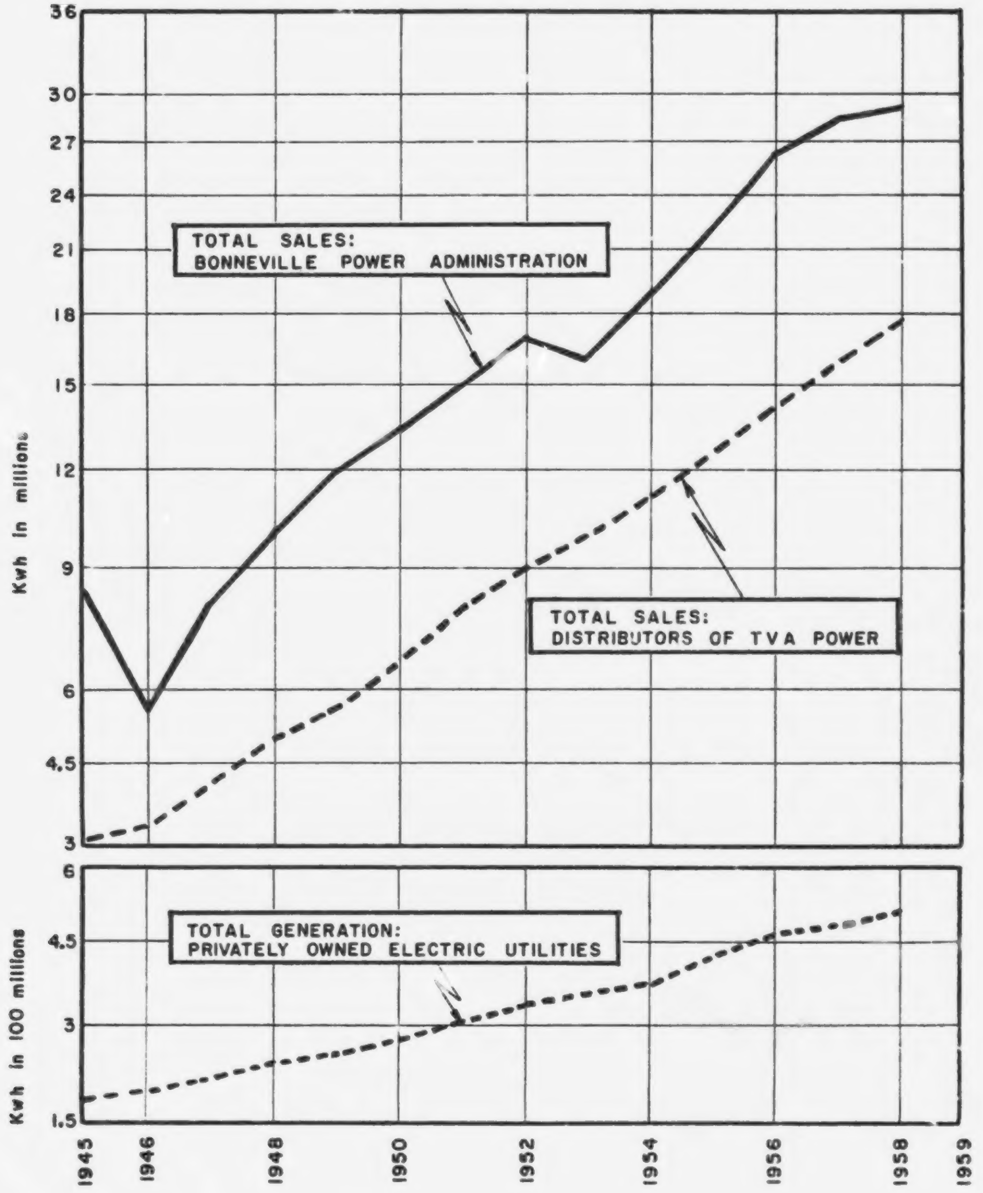
Since the war, TVA area loads—exclusive of enormous Federal demands—have grown at an annual average rate of 12.7 percent and, since 1950, at a 13.2 percent rate—about one-third greater than the national average. The years of slowest growth were during periods of economic recession.

The Pacific Northwest has experienced similarly rapid growth and high use. Sales by BPA rose meteorically from 191.9 million kilowatt-hours in 1940 to 8.5 billion kilowatt-hours in 1945 to 13 billion kilowatt-hours in 1950, and to 28.2 billion kilowatt-hours in 1957, responding to ever-increasing demands which declined but momentarily after the war effort halted. By 1958, regrettably, power production proved "inadequate, and required a reduction in deliveries of interruptible energy to industrial customers * * *," according to the 1958 report of BPA. Up to then, the annual average growth rate since World War II had averaged 13.3 percent, including one year of decline.

The high growth rates in electricity consumption in the TVA and BPA areas occurred at a time of low, promotional rates on the part of cooperative and municipal distributors. Such growth demonstrates that low rates, when coupled with vigorous sales promotion programs, encourage abundant use of electric power. During fiscal year 1958, for instance, the residential customers of TVA power consumed more than 7,000 kilowatt-hours each: more than double the national average. Many cooperative and public agencies retailing BPA power in the Pacific Northwest approximated or surpassed that figure.

CHART E

RATES OF GROWTH IN THREE SECTORS OF THE UNITED STATES ELECTRIC UTILITY INDUSTRY 1945 – 1958



Source: Edison Electric Institute, "EEI Statistical Bulletin - 1958;" Bonneville Power Administration, "Generation and Sales Statistics;" Fiscal Year 1959; Tennessee Valley Authority, "Annual Reports."

Table 2.—*Growth of 3 sectors of the electric utility industry, 1945–58*

[In millions of kilowatt-hours]

Year	TVA [1] distributors (sales)	BPA [2] (sales)	Private power companies [3] (generation)
1945	3,024	8,513	180,926
1946	3,382	5,830	181,020
1947	4,110	8,261	208,106
1948	4,967	10,291	228,231
1949	5,766	11,970	233,112
1950	6,584	13,039	266,860
1951	8,028	15,076	301,845
1952	8,902	17,012	322,126
1953	10,010	16,395	354,272
1954	11,063	18,773	370,970
1955	12,483	21,830	420,869
1956	14,280	25,977	459,015
1957	15,555	28,212	480,943
1958	17,504	28,364	[4] 490,305

[1] Tennessee Valley Authority, Annual Reports (fiscal years), sales of distributors only. Excludes large TVA sales to AEC, other Federal agencies and certain large industrial customers.

[2] Bonneville Power Administration: "Generation and Sales Statistics," fiscal year 1959.

[3] Edison Electric Institute, Statistical Bulletin, 1958, p. 14.

[4] Source: "FPC Statistics of Electric Utilities in the United States—1958: privately owned" (table 23).

The effect of these low rate policies has not been confined to encouraging greater consumption. The resulting increase in per customer usage has, in turn, reduced unit costs and made it possible to maintain low rates and, in numerous instances reduce them to still lower levels during a period when rate increases generally have become increasingly common. Increased revenues and an accelerated rate of expansion in electricity generation also have resulted.

By 1958, as seen in chart F, operating expenses per consumer measured 150 percent those of 1950 for distributors of TVA power. These costs did not include wholesale power charges and represented unit costs to some degree under the control of management. On the other hand, operating expenses per kilowatt-hour had declined from about 2.7 mills to 2 mills. Total 1958 kilowatt-hour sales by all distributors were 275 percent those of 1950.

Results similar to those in the TVA area are reported by retailers of BPA power who have also adhered to principles of low rates and vigorous load promotion.

As a further but less dramatic illustration of the relationship of volume of use to cost, chart G notes the national residential service revenue and use curves, as formulated by FPC. The 1958 average national residential use approaches 230 percent of the 1950 figure, while the average retail unit price decreased from about 2.9 mills to 2.5 mills.

It is not idle to speculate on the far-reaching effects which a low-cost, promotional rate philosophy would have had on our Nation's economy and electric utility industry during these recent years. For the national average not only includes the averages of TVA and BPA high-use and low-cost service areas; it also reflects the "fixed-return" philosophy of the private power industry and its regulators.

Prof. Roy E. Huffman, writing in the journal, Law and Contemporary Problems for a 1957 symposium on "Water Resources" said that the elasticity of demand for electrical energy was an example of a theoretical concept of resources development and use which had "not been accepted by private enterprise." He endorsed the conclusion reached by Ansken and Wormuth in their 1954 study that:

> By showing that lower rates led to increased consumption which more than compensated for rate reduction, it (TVA) stimulated expansion into new markets by privately owned utilities. This is a task which in all probability could have been performed only by public ownership. Public utilities are conservative, partly because of their monopoly position and partly because they know that in the long run, despite all their exertions, their earnings will be pretty largely limited by the regulatory authority to a fixed return on their valuation. The prospective rewards of innovation are much outweighed by the risks. Nor could a regulatory commission constitutionally compel a public utility to embark upon speculative rate reductions in the hope that the resulting increase in consumption would compensate for the lower selling price per power unit. Yardstick competition comes down in the end to the use of public "risk capital" to pilot the way for expansion of private enterprise.[11]

HYDROELECTRIC DEVELOPMENT: 1960–80

The latest estimates of the national hydroelectric potential made by the Federal Power Commission total slightly more than 141 million kilowatts, including about 19 million kilowatts in Alaska. About 29 million kilowatts of this total have been developed. In addition to this 29 million kilowatts, the FPC reports "with some confidence" that 36 million kilowatts in additional capacity will be installed by 1980.[12]

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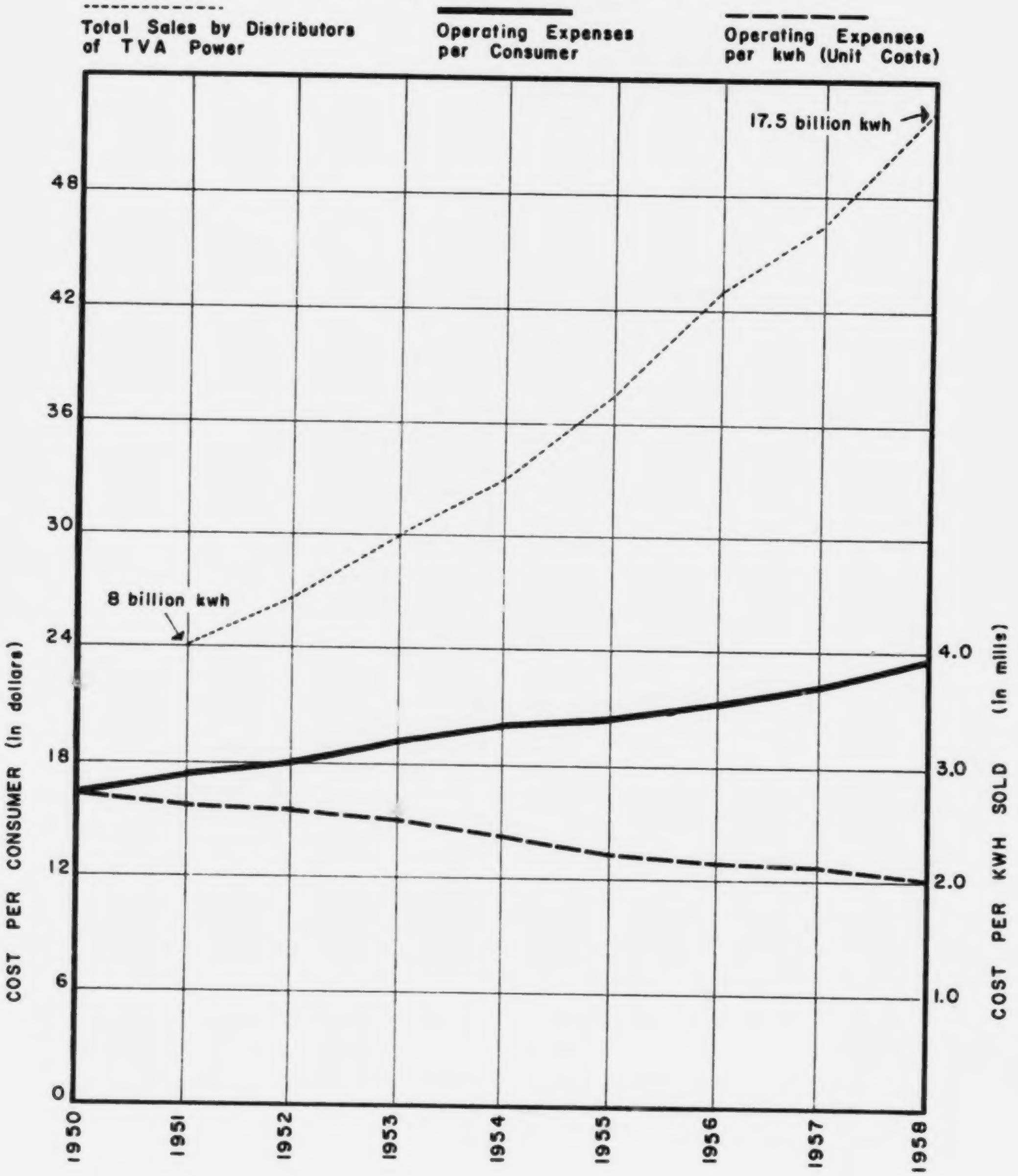
[11] Melvin Anshen and Francis D. Wormuth, "Private Enterprise and Public Policy," 1954, p. 288. Cited in "Role of Private Enterprise," "Law and Contemporary Problems," vol. XXII, 1957, Duke University School of Law, p. 443.

[12] Statement of Francis L. Adams, Chief, Bureau of Power, Federal Power Commission, before the Subcommittee on Automation and Energy Resources of the Joint Economic Committee, Oct. 13, 1959.

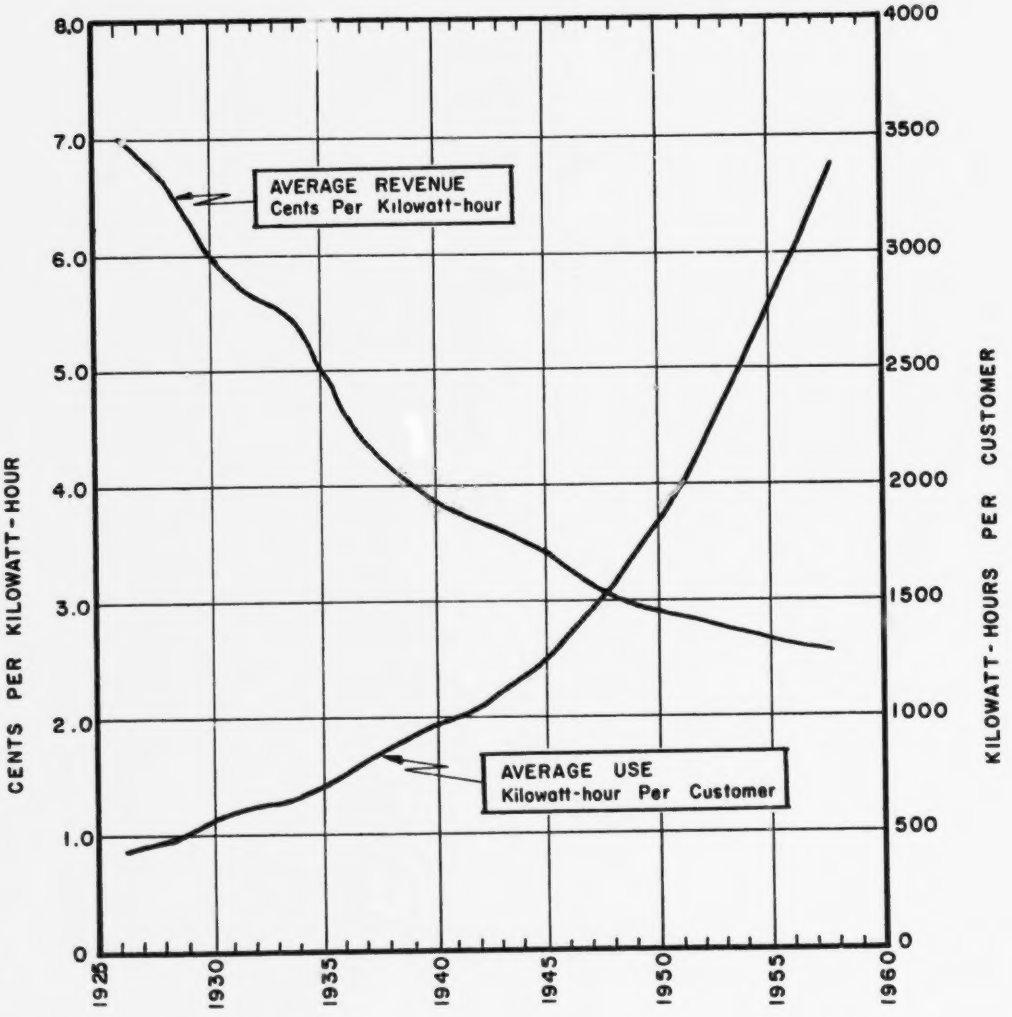
CHART F SALES, PER CUSTOMER COSTS AND UNIT COSTS 1950-1958, DISTRIBUTORS OF TVA POWER



Source: Paper presented by G. O. Wessenauer, Manager of Power, Tennessee Valley Authority, at the Sixteenth Annual Convention of the American Public Power Association, Seattle, Washington, May 26-28, 1959.

CHART G

RESIDENTIAL SERVICE
AVERAGE USE PER CUSTOMER
AND
AVERAGE REVENUE PER KILOWATT-HOUR
TOTAL ELECTRIC UTILITY INDUSTRY
1926-1958



Federal Power Commission, October, 1959

Roughly speaking, the potential hydroelectric capacity of the 48 States is found to be about 24 percent completed, 28 percent anticipated and 48 percent not yet given serious consideration. Alaska's potential has hardly been tapped and Hawaii's is slight—about 300,000 kilowatts.

In its last comprehensive report on hydropower resources—"Hydroelectric Power Resources of the United States, Developed and Undeveloped: 1957"—the FPC described certain standards of definition used in its classifications.

The estimates of undeveloped waterpower. The Commission states—

> include projects on which economic feasibility has been demonstrated as well as projects at sites where physical conditions indicate engineering feasibility and promise at some time of economic feasibility.

The Commission also recognizes that the picture of potential feasible hydro development is "constantly changing".[13]

Hydro estimates revised upward

The FPC, however, is apparently reluctant to point out that the total potential of feasible hydro is "constantly changing" upward. A recent Resources for the Future analysis noted the conservatism of FPC estimates and pointed out that "hydropower resources are at least as much as the estimate, and certainly something more. Just how much more is, again, impossible to say." [14]

In its 1935 "National Power Survey—Interim Report," the Commission concluded that the hydro potential for the 48 States was probably about 53 million kilowatts. This is less than half the 1959 estimate of about 122 million kilowatts for the same 48 States, exclusive of Alaska and Hawaii. In less than 25 years, FPC predictions of the country's hydro potential have gone up by more than 100 percent.

Furthermore, the 1959 figures exceed the Commission's 1957 forward estimate by about 4 million kilowatts. The 1957 estimate, in turn, exceeds that of 1953 by 2.6 million kilowatts. These past 6 years have thus witnessed "additions" of some 6.6 million kilowatts of potential capacity—more than one-fifth of the total hydro capacity that had been developed up to 1958.

Future upward revisions expected

A major reason for the consistent underestimating of future potential appears to have been the propensity to consider sites infeasible or marginally feasible if they, at any time, had been considered of marginal economic value. Thus a Resources for the Future consultant, Bruce C. Netschert, ably pointed out in testimony given before the Subcommittee on Automation and Energy Resources of the Joint Economic Committee in October 1959, that—

> the specter of much higher marginal costs has clearly been in the minds of those who have attempted to project future levels of installed capacity. A survey of all published estimates of installed hydro capacity in 1975 reveals an implied growth rate of 3.5 percent per annum from the base year of each estimate to 1975.

However, the witness said, actual rates of annual hydro capacity growth have been 4.5 percent from 1926 to 1958, 4.3 percent from 1935 to 1945, and 5.5 percent from 1946 to 1958. He estimated that these growth rates would increase to 8 percent from 1958 to 1961.

Private industry and hydropower

FPC's record of making estimates which consistently have had to be corrected upward parallels its record of conservatism in predicting total national use of electricity. Even so, the Commission's views regarding the Nation's hydro potential are more optimistic than those held by a large segment of the private power industry.

One spokesman for the private power companies, in fact, appears to hold (1) that the United States is deemphasizing hydroelectric power generation; and (2) that Russia is deemphasizing hydroelectric power generation for the same reasons. In a paper submitted to the Subcommittee on Economic Statistics of the Joint Economic Committee, Edwin Vennard, executive director of Edison Electric Institute, said that he and a touring group of private power company leaders and industrialists were told in Russia that hydroplants had been found more expensive than steamplants. He said:

> This experience in the relative value of hydro and thermal stations is similar to the experience of the power companies in America. Great improvements have been made in the efficiency of thermal stations, whereas by comparison the increase in efficiency of hydroelectric stations has been slight in the last 25 years.[15]

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[13] Federal Power Commission, "Hydroelectric Power Resources of the United States, Developed and Undeveloped: 1957," 1957, p. 19.

[14] Bruce Netschert, senior research associate, Resources For the Future, Inc., before the Subcommittee on Automation and Energy Resources, Joint Economic Committee, Oct. 12, 1959.

[15] Edwin Vennard, "Evaluation of the Russian Threat in the Field of Electric Power," as contained in "Comparisons of the United States and Soviet Economies," pt. II, Joint Economic Committee, Government Printing Office, 1959, pp. 481-482.

As for the judgment on Russian hydroelectric plans, Mr. Vennard's report neglected to specify the extent of hydro development and rate of growth in the U.S.S.R. in recent years, and omitted reference to the fact that Russia is outdistancing the United States rapidly in current hydro construction. Several Russian projects larger than Grand Coulee (largest in the United States) are presently under construction, and one—Kuibishev—has been completed.

Mr. Vennard's statements with respect to the deemphasis on hydroelectric power station construction in the Soviet Union were not in conformity with information which was given in September and October 1959, to an 11-man U.S. delegation which spent 31 days inspecting Russian hydroelectric power facilities, in behalf of the Interior and Insular Affairs Committee and the Public Works Committee of the U.S. Senate.

This delegation went to the Soviet Union pursuant to Senate Resolution No. 248, and the general manager of the American Public Power Association was a member of the delegation.

At one of the first meetings of the delegation with officials of the Soviet Ministry of Power Station Construction, the delegation inquired as to the accuracy of the reports that the Soviet Union was deemphasizing hydroelectric power station construction. The reply was a flat "No". It was pointed out that the program of building thermal stations was being stepped up, and superimposed upon the hydro program. Moreover, officials of the Ministry of Power Station Construction acknowledged that the cost of power from the thermal plants would be higher than that from the hydro installations, but justified this higher cost on the basis of that fact that the thermal plants could be brought on the line faster and at a lower initial capital investment. The Ministry officials emphasized that they were adding to their thermal plant program primarily because of their desire to speed up the industrialization of their economy.

The figures given by the Ministry of Power Station Construction bear out their contentions that there will be no deemphasis on hydro. During the current 7-year program, the goal of the Soviet Union is to install 60 million kilowatts of new generating capacity, of which 12 million—or 20 percent—will be hydro. This proportion of hydro to steam is exactly the same as that now existing in the Soviet Union.

The inspection by the Senate delegation of 10 different hydro projects, on seven river systems, confirmed the fact that the Russians are going ahead with a very ambitious hydroelectric power construction program.

The Russians also have achieved some notable advances in construction techniques for hydroelectric power facilities. Preformed concrete blocks are already being used extensively in the construction of dams, and Mr. I. T. Novikov, Minister of Power Station Construction, told the Senate delegation that by the advanced use of such blocks a new dam being planned on the Volga River will require only 3 years of construction time, rather than 5 years which would ordinarily be needed. Also, the cost of this project will be cut by 30 percent, he said. Some 65 percent of this structure will consist of preformed concrete blocks.

Suggestions of deemphasis of hydro development in the United States, moreover, appear somewhat paradoxical in the light of the growing annual increments to the nation's hydro capacity discussed earlier. Requests for hydroelectric generating licenses, in fact, have increased out of all proportion to earlier experience. In a recent speech, Elmer F. Bennett, Undersecretary of the Department of Interior, discussed this manifestation of interest in hydro:

> During the 6-year period, 1952–58, 200 applications for projects having an aggregate capacity in excess of 31 million kilowatts were filed with the Federal Power Commission. This is a far greater amount than ever applied for in any previous comparable period of time.[16]

Progress in technology

Technical progress in fields related to water resources development has been crucial to this ever-widening horizon for hydropower development. It will prove decisive also in terms of future prospects and planning. This is particularly true in connection with steamplant technology, involving both water use and electricity generation, and water storage technology. A major study of the subject, sponsored by Resources for the Future and published earlier this year—"Technology in American Water Development"—analyzed technology's impact on energy consumption. The authors, Ackerman and Lof, concluded that:

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[16] Elmer F. Bennett, Undersecretary, Department of Interior, in an address at the Utility Companies of Iowa Management Conference, Des Moines, Iowa, Oct. 12, 1959.

> The steadily increasing efficiency with which electricity is generated has resulted in a gradual reduction in cost so that its use has gained at a greater rate than other sources of energy.[17]

As to continuing technological advances in hydropower, the authors pointed to developments which include:

1. The "rapid increase" in the capabilities of earthmoving machines: 50-ton dump trucks, conveyor belts, scrapers, bulldozers, and the like—equipment which has contributed striking increases in efficiencies in dam construction.

2. Advances in design, utilization of materials, and site preparation for concrete dams, affording new, cheaper ways to store and most effectively use river flows. New construction in the United States, the study notes, has been more conservative toward design innovations up to now, than in Europe. A major reason for the conservatism was found to be that:

> * * * most European dams are designed as well as constructed under a competitive bidding system, whereas a Government agency or an operating private corporation usually designs the structures in the United States. Hence there is a particular incentive in Europe for developing new types of structures permitting major materials savings.[18]

3. Development of integrated regional water systems, based specifically on the extensive experience of TVA in exploiting the economies possible in such a system, with hydro operating more often at capacity, new hydro units at sites previously considered economically impractical, and new methods of managing waterflows being cited as important contributors to hydro's more favorable position.

Technical progress likewise has resulted in the introduction of pumped storage projects in the United States. Here, waterflow is reversed for added reservoir storage—when electricity demand is low—and subsequently released through the turbines when demand is high.

High-voltage transmission over long distances will also enhance hydropower development. The United States at present has a line transmitting at 345,000 volts and tests are underway to study the feasibility of transmission voltages exceeding 460,000 volts.

Voltages exceeding 345,000 volts are already in use in other countries, including the U.S.S.R. Maximum feasible transmission distances abroad also exceed those in the United States (266 miles, from Hoover Dam to Los Angeles). Sweden has built a project, for example, which uses a 380-kilovolt line to deliver large amounts of power 600 miles from hydropowerplants to load centers. The Soviet Union also has a 600-mile line.

"Maximum" hydro development uncertain

Technical progress will, as it has in the past, contribute to the development of economically feasible hydroelectric potentials where they did not exist previously. The important implication of this fact—that the maximum economic potential is unknown at the present time—should be kept clearly in mind in planning for water resources development.

Hydropower for peaking purposes

Hydro necessarily will represent a relatively small share of the Nation's total electricity generation, and the bulk of the massive future demands will be met by thermal generation. Regional exceptions, especially the Pacific Northwest and Alaska, will remain for some time, however.

Nevertheless, the "newer steam technology," in the words of Ackerman and Lof—

> in almost every instance may be interpreted as having a favorable effect upon the development and management of multiple-purpose water facilities and multiple use of water in the United States.

They conclude that:

> In spite of the vast expansion of steampower generating facilities now anticipated, steamplants are not expected to displace hydroelectric plants, because of the much enhanced value of waterpower for peaking purposes on systems within reach of both types of generation.[19]

This supports the personal view of the Chief of the Division of River Basins of FPC who pointed to the two immutable virtues of hydro:

> * * * hydropower, unlike fuel-produced power including atomic, is a renewable resource and once developed continues to produce without depletion of available resource reserves. Furthermore, as already noted, hydroelectric power can serve an important and useful place in

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[17] Ackerman and Lof, op. cit., p. 300.

[18] Ibid., p. 233.

[19] Ibid., p. 319.

regional power economics by carrying the variable demands of peakloads.[20]

Regional hydro development

Just where added hydro capacity will be installed by 1970 and 1980 is difficult to judge. One guide is provided by the FPC in its breakdown of developed and undeveloped power, based on geographic areas and States. This breakdown is found in table 3, together with a listing of the percentages of hydro development for the United States, exclusive of Alaska and Hawaii.

A major water development project usually seems to take 10, 15, or more years to materialize, once preliminary consideration is initiated. Thus, the FPC felt that it could "with some confidence" predict a 1980 figure of 36 million kilowatts of additional hydro. However, it should be pointed out that the pace of development and the regional distribution of hydroelectric installations will depend in great part upon the policies adopted by the Government and private industry as to the aggressiveness with which they move to meet the Nation's water and power needs.

Regional development rates will also depend upon the extent to which private and public agencies within the regions turn to hydroelectric power for use as peaking capacity. In this connection, governmental policies such as we have had in more recent years, which are generally opposed to Government initiative in hydro development, for reasons having little to do with engineering considerations, obviously will result in a slower rate of growth than more positive and aggressive policies.

Parenthetically, it should be pointed out that past technological advances in hydro development have been generally credited to public agencies. The highest voltage transmission line, 345 kilovolts, is part of the transmission grid of the Bonneville Power Administration. The "pioneer" transmission line from Hoover Dam, still the Nation's longest and built in the mid twenties, was constructed by the city of Los Angeles. The role of the Tennessee Valley Authority in both hydro and steam technological development, furthermore, has been a leading one. It is exemplified in the planned TVA steamplant at Paradise, Ky., designed to use what will be the largest generating unit in the United States—600,000 kilowatts. Similar pioneering work in hydropower development has been carried on by local public agencies in the Pacific Northwest.

TABLE 3.—*Percent development of hydroelectric power resources, Jan. 1, 1957, by geographic divisions and States*

Division and State	Developed installed capacity, kilowatts	Undeveloped estimated capacity, kilowatts	Total estimated capacity, kilowatts	Percentage development
United States	26,547,845	90,599,800	117,147,645	23
New England	1,535,710	2,728,400	4,264,110	36
Middle Atlantic	1,482,531	8,509,500	9,992,031	15
East North Central	935,484	2,798,650	3,734,134	25
West North Central	1,315,046	6,201,650	7,516,696	17
South Atlantic	3,625,768	7,585,700	11,211,468	32
East South Central	3,581,508	3,920,300	7,501,808	48
West South Central	949,620	3,800,700	4,750,320	20
Mountain	3,707,408	21,332,950	25,040,358	15
Pacific	9,414,770	33,721,950	43,136,720	22
New England:				
Maine	500,211	1,262,600	1,762,811	28
New Hampshire	447,823	594,500	1,042,323	43
Vermont	201,775	453,700	655,475	31
Massachusetts	234,616	259,500	494,116	47
Rhode Island	6,792	0	6,792	100
Connecticut	144,493	158,100	302,593	48
Middle Atlantic:				
New York	1,034,624	5,003,000	6,037,624	17
New Jersey	8,678	225,000	233,678	4
Pennsylvania	439,229	3,281,500	3,720,729	12
East North Central:				
Ohio	13,874	341,000	354,874	4
Indiana	35,464	600,000	635,464	6
Illinois	43,131	1,208,800	1,251,931	3
Michigan	423,909	328,050	751,959	56
Wisconsin	419,106	320,800	739,906	57
West North Central:				
Minnesota	189,670	230,850	420,520	45
Iowa	142,421	454,200	596,621	24
Missouri	196,800	2,937,800	3,134,600	6
North Dakota	240,000	358,800	598,800	40
South Dakota	333,046	1,227,500	1,560,546	21
Nebraska	207,199	702,500	909,699	23
Kansas	5,910	290,000	295,910	2
South Atlantic:				
Delaware	600	0	600	100
Maryland	274,165	360,000	634,165	43
District of Columbia	3,000	0	3,000	100
Virginia	423,054	1,205,900	1,628,954	26
West Virginia	207,560	2,160,000	2,367,560	9
North Carolina	1,226,050	973,900	2,199,950	56
South Carolina	961,729	786,200	1,747,929	55
Georgia	518,449	2,009,700	2,528,149	21
Florida	12,661	90,000	102,661	12
East South Central:				
Kentucky	542,380	1,320,500	1,862,880	29
Tennessee	1,738,788	507,300	2,246,088	77
Alabama	1,300,340	1,682,600	2,982,940	44
Mississippi	0	409,900	409,900	0
West South Central:				
Arkansas	390,740	1,483,500	1,874,240	21
Louisiana	0	45,500	45,500	0
Oklahoma	166,500	767,000	933,500	18
Texas	392,380	1,504,700	1,897,080	21
Mountain:				
Montana	851,510	5,799,100	6,650,610	13
Idaho	778,080	7,964,450	8,742,530	9
Wyoming	143,237	977,900	1,121,137	13
Colorado	248,365	1,801,400	2,049,765	12
New Mexico	24,830	187,500	212,330	12
Arizona	982,790	3,390,700	4,373,490	22
Utah	88,376	1,077,400	1,165,776	8
Nevada	590,220	134,500	724,720	81
Pacific:				
Washington	4,193,996	18,722,800	22,916,796	18
Oregon	2,043,954	6,292,850	8,336,804	25
California	3,176,820	8,706,300	11,883,120	27

Source: Federal Power Commission, "Hydroelectric Power Resources of the United States, Developed and Undeveloped: 1957," table 15, p. 196.

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[20] Frank L. Weaver, Chief, Division of River Basins, Bureau of Power, Federal Power Commission, "Outlook for Hydroelectric Development," fifth annual conference, "Atomic Energy in Industry," National Industrial Conference Board, 1957, p. 10.

THE NATURE OF FUTURE PRODUCTION

It was pointed out earlier in this memorandum that electricity generation by the utility industry from 1946 to 1958—the postwar period—has been about 10 percent. The Edison Electric Institute's report that both installed capacity and electricity generation for 1959 will exceed that of 1958 by about 10 percent has also been noted.

It has likewise seemed reasonable to project this annual average growth rate. By so doing, our Nation's power supply capacity will compute to about 405 million kilowatts by 1970 and to about 1,270 million kilowatts by 1980. Electricity generation, gaining 10 percent each year, would approximate 2 trillion kilowatt-hours by 1970 and 5.2 trillion kilowatt-hours by 1980, based on the utility industry's 1958 generation of more than 644 billion kilowatt-hours.

In terms of new additions to capacity, this high rate of growth would mean more than 260 million new kilowatts by 1970, and about 1,130 million new kilowatts by 1980. The bulk of these additions would be in thermal power.

The role of nuclear power

There is little question that between now and the year 2000 nuclear power will assume an important role in helping to provide the massive additional thermal capacity which will be required. Although the United States has very large reserves of fossil fuels recoverable at economic costs, there are substantial reasons for moving ahead vigorously with the development of low-cost nuclear power.

Thus, in their paper presented to the second United Nations Conference on the Peaceful Uses of Atomic Energy, in September 1958, W. K. Davis and U. M. Staebler of the U.S. delegation observed that:

> The size of economically recoverable reserves of [fossil] fuel in the United States is uncertain. The chief variables are the quantities beneath the ground, future rates of use how much we may be able to import, and what the economy can afford for recovery. If our present notions about these factors are correct, it can be estimated that usable fuel reserves within the borders of the United States recoverable at twice present costs will be exhausted in about 50 years.
>
> The situation may be even more serious than is indicated in these estimates. The critical period for the introduction of new sources of energy will occur when the overall rate of production of fuels can only be increased to meet greater demands at substantially higher unit costs—not when the reserves recoverable at a given price are actually exhausted. The time before this situation will arise is even more difficult to estimate than the size of the reserves and increases in use and will be different for the various fuels. However, it appears certain to occur for some fuels in about 15 or 20 years and probably for all inside of 30 years.

Davis and Staebler pointed out that inasmuch as nuclear energy can be expected to meet only a portion of future electric power requirements and since these in turn amount to only about 14 percent of present total energy requirements—

> it therefore becomes of the greatest importance that nuclear energy take up the burden where it can be effective in order to conserve fossil fuels for uses for which they are essential.

A related point was made recently by Philip Mullenbach (at one time economist with the Atomic Energy Commission, former staff director of the National Planning Association's comprehensive project on the productive uses of nuclear energy and presently consultant to the Twentieth Century Fund on its Nuclear Energy Study). Mr. Mullenbach, in an address of August 25, 1959, to the American Bar Association section on mineral and natural resources law remarked:

> Why is it economically important for the United States, on domestic grounds alone, to maintain a strong sense of urgency in the development of low-cost, competitive nuclear power? The main reason, it seems to me, is the need for bringing into our national energy situation an important new source of energy, one that will help to restrain the progressive upward trend in the real prices of conventional fuels.
>
> Despite our favorable reserves of coal, oil, and natural gas, and despite increasing labor productivity, the real price of each of these has been rising. This is partly a matter of an inadequate overall energy policy. For example, the prices of natural gas have been rising—despite the large reserves of gas and the efforts of the Federal Power Commission to restrain the increase. Also, the pattern of domestic oil prices has been partly insulated from the salutary effect of low-cost foreign oil available in this hemisphere. Moreover, public and private efforts to develop economic methods of producing oil from western shale have about come to a halt. Looking at coal, we are impressed by the vast reserves available at low cost, yet the record of real prices shows a significant upward trend approaching 1.5 percent annually (compound).
>
> The conclusion seems clear: despite favorable reserve aspects, the real prices of primary energy are rising and may continue to do so under present policies. Low-cost nuclear energy, developed without delay, can and should help to restrain this upward drift. It would also help to achieve important foreign policy objectives in Western

Europe and the free world generally, as well as assure more efficient use of our domestic nuclear resources.

If the development of competitive nuclear power "without delay" should effect sufficient restraint on the prices of fossil fuels to save only one-tenth of a mill per kilowatt-hour of electrical energy, by 1975 this would represent savings to the consumers of the United States on the order of $200 million per year, and more each year thereafter. By the year 2000, the cumulative savings would bulk very large indeed, easily justifying the public investments necessary if atomic power development is to be accelerated, and carried forward with "a strong sense of urgency."

It is very difficult to make useful predictions of the rate at which the use of nuclear energy for electricity production will grow in the United States. The relatively few sizable nuclear powerplants presently in operation, under construction or planned are developmental plants and in all cases are uneconomic. The additional nuclear power capacity installed in future years will continue to be relatively small until it is learned how to design a plant which can be built and operated to produce power at costs competitive with or cheaper than those for conventional thermal plants. This point will be reached at different times in different regions of the United States and, generally speaking, will be attained first in those areas in which the delivered costs of the fossil fuels are relatively high.

Before this point can be reached, there needs to be considerable progress made on the solution of existing technical problems which will permit the design of plants which can be built and operated at unit costs significantly below those attainable with present nuclear powerplant technology. The rate at which this progress will occur and will be demonstrated is heavily dependent upon policies adopted by the Federal Government, as well as by the utility industry.

The bulk of research and development work necessary to solve these technical problems is being financed with Federal funds and most of the developmental power plants being built or planned are possible because of Federal financial assistance or underwriting in one form or another.

If the Government should decide upon an aggressive, accelerated program of nuclear power development, economic atomic powerplants will be attained earlier than if a more deliberate approach is followed. Thus, in his testimony before the Joint Economic Committee of the U.S. Congress on October 16, 1959, Dr. Walter Zinn, of Combustion Engineering, Inc. stated:

> * * * One can only conclude that the prospects are good that the next generation of large-size [nuclear] plants will be competitive in some areas of the United States. Since these large-size plants are not as yet in the blueprint stage, and since it takes 4 years' time to construct a powerplant, we cannot expect an actual demonstration of competitive nuclear power before 1965 or 1966. The actual time may be delayed beyond this point because the present U.S.A. program envisages the construction of a number of prototype plants incorporating the latest technical improvements as the next phase in the development of nuclear powerplants. It is entirely possible that the construction of large-scale plants will be delayed until the prototype plants can be built and operated, in which case we should not expect competitive power from such large plants before 1970.

Dr. Zinn is generally regarded as one of the foremost U.S. experts in power reactor technology.

His judgments seem confirmed in a general way by a report made on November 3, 1959, to the Atomic Industrial Forum by Dr. Frank Pittman, director of the Division of Reactor Development of the Atomic Energy Commission. In reporting on the conclusions of a recently completed series of studies by the Commission, Dr. Pittman said that, assuming success in necessary further research and development work, construction could begin in 1965 on a 300,000 electrical kilowatt plant, using a boiling water reactor and nuclear superheat, which would produce power at an estimated cost of 6.75 mills per kilowatt-hour, assuming an 80 percent plant factor and private financing. This estimate of possible or probable future development seems generally consistent with Dr. Zinn's forecast of nuclear powerplants which are economically competitive in some regions of the United States by 1970 if a deliberate approach is taken by the Atomic Energy Commission. This is the type of approach the Commission has been taking.

Translating this estimate of 7-mill power by 1970 into forecasts of future installed nuclear power capacity is difficult because of the numerous assumptions required. Dr. Zinn made what he called an "arbitrary estimate" that "in 1980, 20 percent of all electrical generation will be by fission reactors." He termed this "an optimistic assumption." As indicated previously in this paper, Dr. Zinn applied his 20 percent estimate to the Federal

Power Commission's 1955 forecast of 1,800 billion kilowatt-hours of total electrical energy production in the United States by 1980 to derive a nuclear power production estimate of 360 billion kilowatt-hours for that year.

His estimate, however, can hardly be termed optimistic, because the base which he used—the FPC estimate—is almost certainly much too low. In its September 14, 1959, issue, Electrical World projected a total electrical energy production of 2,400 billion kilowatt-hours by 1975; if this curve is extended to 1980, a forecast of about 3,500 billion kilowatt-hours is derived. Dr. Zinn's "arbitrary estimate" of 20 percent applied to this figure results in a quantity forecast almost twice as large as Zinn's—700 billion kilowatt-hours of nuclear power production in 1980.

Somewhat similar results are obtained by consideration of another estimate, which was based upon a highly detailed analysis of the probable future trends of nuclear power costs and conventional fuel costs, as well as the probable growth of electric energy production. In his paper on "Nuclear Power and the World Market," presented to the 1957 meeting of the National Industrial Conference Board, Karl M. Mayer, at that time consultant to the Stanford Research Institute, predicted that nuclear power generation would account for about 21 percent of total electricity generation in the United States by 1980. Mayer also relied heavily upon FPC forecasts of power consumption and assumed a total production of 1,795 billion kilowatt-hours in the United States by 1980, and so computed a total nuclear power production by that date closely similar to Zinn's more recent figure.

However, in making his prediction, Mayer assumed that 7-mill nuclear power would not be attained until 1975, whereas Zinn's recent testimony and the recent report by Pittman indicate that, for forecasing purposes at least, 7-mill nuclear power by 1970 is a reasonable and possibly conservative assumption. Making this assumption, it would appear reasonable to forecast that nuclear power production will account for about 20 percent of total production by 1975, rather than 1980, if Mayer's other assumptions are accepted. Applying this figure to Electrical World's forecast of total electricity generation of 2,400 billion kilowatt-hours in 1975 would give a nuclear power production estimate of 480 billion kilowatt-hour by that year.

These adjustments to the Mayer and Zinn forecasts appear to be reasonable and the main point they illustrate is that both the Zinn and Mayer estimates are probably too low. This point of view becomes even more compelling if a continued 10 percent per year growth in utility electricity generation is assumed, in which case a figure of about 5,200 billion kilowatt-hours by 1980 is derived. Twenty percent of this total would give a forecast of 1,040 billion kilowatt-hours of nuclear power production in 1980—almost twice the total electric energy production by utilities in 1957, and three times the Zinn estimate.

It should be pointed out that there are other factors than the rate of technical development which will affect the rapidity with which nuclear power becomes economic, and at least two of these also are subject to public policy decisions. One is the extent to which this country develops regional wholesale power supply systems. At present, the economics of nuclear power are favorably affected by the construction of very large plants and by their operation as base load stations, more so than in the case of conventional thermal plants.

Large nuclear stations, of 1 million to 3 million kilowatts capacity each, will be feasible only on large, integrated power generation and transmission systems. The use of nuclear plants for base-load energy supply, even in smaller size ranges of 500,000 to 1 million kilowatts, likewise will be practicable only on large power systems.

Thus, the degree to which the country develops regional giant power supply systems probably will affect importantly the unit costs of nuclear power and, accordingly, the rapidity with which it comes into common use.

Another factor of importance is the form of financing adopted for the giant power stations of the future. If present indications hold true, nuclear plants in general will have higher capital costs and lower fuel costs than most conventional thermal plants in this country. Consequently, policies which reduce the cost of money for capital financing would have a more favorable effect on unit nuclear-power costs than on conventional power costs. If there should be an increased tendency to build publicly financed nuclear powerplants and/or a policy adopted for financing the giant wholesale power supply systems of the future almost entirely through bond financing—which would result in much lower private financing costs—then the unit costs of nuclear power would be reduced significantly relative to those for conventional thermal power and, again, the earlier utilization of nuclear power on a large scale would be favored.

Because of the number of assumptions which must be made, any estimate of nuc'ear-power production in 1980 is necessarily conjectural. Considering the obvious conservatism built into the Zinn and Mayer estimates because of their use of FPC total power production forecasts, and because Mayer assumed 7-mill power coming in no earlier than 1975, a more reasonable guess would seem to be about 700 to 750 billion kilowatt-hours of nuclear-power production in 1980. This would represent a sizable industry, as it would exceed by a substantial margin the total electric utility production in 1958 of 641 billion kilowatt-hours.

The corresponding nuclear plant capacity would approximate 120 to 130 million kilowatts, assuming an average 70-percent plant factor. It is of interest to note that this projection falls at the upper end of the range of 52 to 135 million kilowatts of nuclear capacity by 1980 which was used by the Panel on the Impact of the Peaceful Uses of Atomic Energy in its report of January 1956 to the Joint Committee on Atomic Energy.

However, while seemingly reasonable from a "numbers" standpoint, the construction of more than 100 million kilowatts of nuclear capacity during the 10-year period 1970–80 would be no small undertaking. It will be much more likely of accomplishment if the AEC will take a truly vigorous approach to its job and acquire "a strong sense of urgency."

The Commission should aim for the attainment of competitive nuclear power in the United States by 1965–66, as Dr. Zinn indicated is entirely possible. That this achievement would be highly desirable on economic grounds alone, quite apart from important foreign policy considerations, is indicated by the large savings attainable as soon as nuclear-power costs are brought down to the point that they begin to inhibit further price increases for the fossil fuels. The economic benefits will be particularly important in areas such as New England where delivered fossil fuel costs are already high.

Large-scale generation transmission

A means to cheaper, better, and more plentiful electric service using large-scale generation and transmission was proposed and described almost 35 years ago by Gov. Gifford Pinchot of Pennsylvania, conservationist of the administration of President Theodore Roosevelt. In general, Governor Pinchot's 1925 report of his giant power survey board to the General Assembly of the State of Pennsylvania contains underlying principles which are generally relevant to the contemporary situation. Referring to the State of Pennsylvania, for example, the report includes such comments as:

> Mass production of thermal power by giant power-generating stations of great capacity in or near the coalfields, supplying large capacity transmission lines connecting with all other major transmission lines in the State;
>
> Creation of a common pool of power into which current from all sources will be poured, and out of which current for all uses may be taken. This is to be secured by making these giant power companies common purchasers of surplus power from all generating stations in the State and common sellers to all distributing systems in the State;
>
> Free access by every waterpower and steam-generating station to every potential purchaser, which means every distributing system in the State which supplies the consumer, through making all major transmission lines common carriers;
>
> Systematic extension of service lines throughout rural areas by farmers' mutual companies and rural electric districts served on an equality with all other distribution systems by current from the giant power companies or any other generating stations delivered over the common-carrier transmission lines.[21]

Mr. Leland Olds, former Chairman of the Federal Power Commission, in 1956 pointed out to a Senate subcommittee that Governor Pinchot further distinguished between "giant power," dealing with great pools of power out of which power for all uses are taken, and the private power companies' "superpower" idea involving merely interchange among systems of small quantities of surplus power.[22]

Testimony by power company officials at the same hearing indicated that private industry—31 years later—had come to consider regional, large-scale generation and transmission not only as technically feasible but highly desirable. They described in detail the engineering and economic logic which supports the development of "giant power" wholesale supply systems in the course of an unsuccessful endeavor to remove the teeth of major provisions of the Public Utility Holding Company Act of 1935.

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[21] From the Governor's message of transmittal of "The Report of the Giant Power Survey Board to the General Assembly," Commonwealth of Pennsylvania, February 1925, pp. v–vii.

[22] Hearings before a subcommittee of the Committee on Interstate and Foreign Commerce, U.S. Senate, on "Amendments to Public Utility Holding Company Act, 1935," Government Printing Office, 1956, p. 317 ff.

For example, Mr. Harllee Branch, Jr., president of the Georgia Power Co. and president of the Edison Electric Institute at the time of the 1956 hearings, analyzed the need for "group planning, power-pooling contracts, and joint ownership of generating plants" as "logical extensions" of the history of power distribution in America. He said:

> By this method, utility companies, even large ones, but particularly the medium and smaller sized companies, can obtain for their customers the economies of large-scale power production at points where fuel prices and other power-production factors are most favorable—including not only the most favorable apparatus expense, but also favorable financing costs.[23]

Mr. Branch went on to say that—

> Companies not under the jurisdiction of the Holding Company Act naturally hesitate to come under its provisions. For that reason the Holding Company Act tends to retard and discourage the joint ownership of generating plants, especially by the smaller companies.

This testimony by private utility management tends to confirm the conclusion reached by Ackerman and Lof with respect to power supply in the United States:

> A number of electric utility companies were under holding company control previous to 1935. * * * most of them have divested themselves of holding in such a way that former subsidiaries now are exempted from Federal regulation, and are entirely under State jurisdiction. Since State boundaries make no more logical electric service areas than they do water control regions, the optimum geographical extent of the service area is achieved only accidentally.[24]

The authors pointed out that 60 percent of the private power companies in 1957 reportedly had peakloads of less than 125,000 kilowatts, while only 14 percent were reported to have more than 500,000 kilowatt peakloads. Ackerman and Lof, in discussing the need for more rational distribution of electricity in the United States, went on to say that—

> While the optimal size of a closely coordinated distribution system may be no more than regional, few of the country's systems in 1958 reached this scale. The Federal Power Commission's responsibility to secure interconnection and coordination of electric facilities applies only to interstate utilities, and hence is not applicable to many of the existing systems. It also appears that this authorization has not been vigorously administered by the Commission.[25]

The nature and number of generating plants throughout the country will to a great extent depend upon the manner in which the need for large-scale generation and transmission is met. The economics of nuclear power, for instance, generally favor very large plants operated on baseload. Such large baseload plants will be feasible only in large, integrated generation and transmission systems. Similarly, the value of hydro capacity for peaking energy is greatly enhanced when it is integrated into a regional supply system. As is well established, substantial economies are possible through the use of very large coal-fired plants and these, too, are feasible only for large, integrated generation and transmission networks.

From the standpoint of water resources, there is the further compelling consideration that there is a limited number of sites in any region with an adequate supply of cooling water for a multimillion-kilowatt thermal generating station. One can foresee the day when regional giant power grids will be necessary if we are to be able to locate large and efficient generating stations at the site of adequate water supplies and economically transmit the power produced to the markets for it.

The achievement of a more rational organization of wholesale power supply is now generally recognized as desirable and should be considered a national goal. It would make possible improvements in fuel utilization, transmission direct from power plants at coalfields to distributors, increases in thermal efficiency, reductions in unit capital costs, and other economies, realizable only through large-scale production and the regional integration of wholesale power supply.

THE NATURE OF FUTURE CONSUMPTION

Giant strides in technology also illustrate a new scope of residential use of electricity which, except in TVA and Pacific Northwest areas, was virtually untried a decade or so ago—the all-electric home. The realization of this concept on a wide scale will go hand in hand with the development of low-cost power supplies of electricity on regional levels.

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[23] Ibid., p. 209.

[24] Ackerman and Lof, op. cit., footnote, p. 505.

[25] Ibid., p. 585.

Estimates of future types of use

The increasing requirements of residential customers is to some extent mirrored in predictions made by the FPC and the Electrical World.

The latter, in its September 1959 issue, forecast a rise in utility residential sales from 159 billion kilowatt-hours in 1958 to 441.2 billion kilowatt-hours in 1970 and 659.9 billion kilowatt-hours in 1975, an increase of about 315 percent in 17 years, as compared with a total predicted national increase of about 277 percent

The FPC predicts a lesser increase for its "nonfarm-residential" and "farm, excluding irrigation and drainage pumping" categories, but a significant increase nevertheless. According to its 1959 projections, these two categories will jump from about 154 billion kilowatt-hours in 1958 to 552 billion in 1980, an increase of some 258 percent in 22 years. The FPC figures compute to an overall national increase of about 216 percent for that period.[26]

Obviously, in planning water resources development it is necessary to determine as accurately as possible future residential power requirements. It is possible that both of the cited predictions underestimate future residential requirements. And there is every indication that a long period of growth in residential electricity use lies ahead. This is inevitably true if we assume a rationalization of wholesale power supply and the provision of an abundance of low-cost power to all distributing utilities, and adoption by the latter of a sales philosophy of low, promotional rates and high consumption.

The relationship of abundance and low cost to use is illustrated by the experience of the Bonneville Power Administration. In a 1957–58 survey, BPA said:

> Since the close of World War II, when electric appliances were again available in quantity, use per customer [in the BPA area] has steadily climbed from about 2,800 kilowatt-hours per year in 1945 to nearly 8,500 kilowatt-hours in 1957, a growth of 475 kilowatt-hours per year. In contrast, the average U.S. domestic use increased only 165 kilowatt-hours per year, from 1,300 in 1945 to 3,265 kilowatt-hours per year in 1957.[27]

In the TVA power service area even more striking relationships are found. There the average 7,189 kilowatt-hours used by the average consumer during 1958 was nearly 2½ times the national average. Much of this difference was due to the increasing utilization of electrical space heating—up to 90 percent of new housing in some areas being electrically heated—which was made possible by the availability to the homeowner of electricity at low rates.

Nationwide, the use of air-conditioning equipment also gains steadily each year. Only 43,000 room air conditioners were reportedly sold in 1947, compared to about 1,230,000 only 7 years later. Sales of larger, central unit air-conditioning systems now annually number in the hundreds of thousands. And even electric automobiles—recharged at nighttime "off-peak" hours—are now receiving increasing attention.

In sum, efficiencies in generation and transmission of bulk power supply, if effected and if passed on to consumers, will stimulate ever-increasing power consumption by residential users.

By 1980, it seems reasonable to expect close to 40 percent of electricity consumption to be residential, compared to the 27.97 percent share reported for 1958 by the Electrical World. The president of Edison Electric Institute, in 1958, predicted that residential and rural use of electricity would reach 1.1 trillion kilowatt-hours in sales in 1979, more than one-third of the 3 trillion kilowatt-hours in sales he predicted for the United States in 1979.[28]

In commenting on estimates of growth, the National Rural Electric Cooperative Association has pointed up the future of residential consumption:

> The figures show that when we reach 1970, the average home will be using about 7,323 kilowatt-hours of electricity per year as compared with 2,528 kilowatt-hours in 1954. Its use will nearly triple in the next 16 years. But, when we project our view to the year 2000, only 45 years away—we find an indication that the average annual home use of electricity may reach not 33,000 kilowatt-hours a year, as we of NRECA estimate, but 50,000 kilowatt-hours. This opens wide the opportunity for our imagination to

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[26] Federal Power Commission, release No. 10,480, June 17, 1959, table 1.

[27] Bonneville Power Administration, "Advance Program: 1968–69," 1958, p. 6.

[28] New York Times, June 9, 1958, p. 47.

conjure up what that electrical magician will do for our homes of the future.[29]

Ackerman and Lof conclude that the heavily increased domestic electric demand will significantly affect the demand for water, observing—

> that the current *water demand for residential electrical generation exceeds that for water actually domestically* used by several billion gallons per day. [Emphasis supplied.]

Furthermore, the trend toward large steam-electric generators for base load requirements and toward hydro for peaking, when—

> coupled with the peaking characteristics of heavy air-conditioning or electric heating loads, will affect the design and operation of reservoirs and hydro generation plants. Where applicable, it also will affect the increased use of water in these facilities as well as in thermal powerplants. Increased domestic electric use, therefore, has a marked influence on the rate of exploitation of water and the incidence of demand.[30]

CONCLUSION

It is obviously difficult to forecast future needs and sources of electricity with a great sense of certainty. For purposes of planning future water development, however, it would seem advisable to regard the commonly used projections, such as those of the Federal Power Commission and Electrical World, as being too low. They have erred on the side of conservatism in the past and it is reasonable to assume that actual future power demands also will exceed current forecasts.

This memorandum has pointed to the country's historical expansion in the use of electricity, and has suggested that the approximate 10 percent annual rate of increase recorded by the United States since World War II may well continue for many years to come. There seems to be no valid reason to predict a lower percentage figure.

It is evident that hydropower will continue to be an important and integral part of the national power supply picture. Less than one-fourth of the currently estimated potential capacity of the country has been developed, and the total potential capacity itself doubtless will continue to increase as further technological developments occur. FPC projections of future additions to developed capacity assume a lesser rate of growth than in the past and appear to be much too low. This judgment is strengthened by the fact that the inevitable trend to very large thermal stations will increase the value of hydro and further encourage the development of additional hydro capacity.

The American Public Power Association commends the Senate Select Committee on Water Resources for its interest in a field where, in our opinion, Federal responsibilities in recent years have been neglected. There is great need for a purposive public policy on water resources development. Related to this is the equal need for policies and programs to facilitate the development of more rational and efficient organizations for electric power supply. The select committee's investigations and study of the needs for water resources development will contribute guidance and information of great value in developing policies in both areas appropriate to contemperary conditions.

In addition, for the formulation of informed policies in the field of power, including such areas as atomic power development, a comprehensive and expert survey of future energy needs and resources is essential. The last such study made was that by the President's Materials Policy Commission (Paley Commission) which was published in 1952. Another such survey, bringing up to date the information on resources and probable needs, is overdue.

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[29] National Rural Electric Cooperative Association, "The Role of the Rural Electrics in the Atomic Age," report to the 13th annual meeting, 1955, p. 11.

[30] Ackerman and Lof, op. cit., pp. 145-146.

FUTURE POWER REQUIREMENTS OF THE RURAL ELECTRIFICATION PROGRAM

DEPARTMENT OF AGRICULTURE,
Washington, D.C., October 7, 1959.

Hon. ROBERT S. KERR,
Chairman, Select Committee on National Water Resources,
U.S. Senate.

DEAR SENATOR KERR: Your letter of July 6, 1959, asked us to estimate the REA borrowers' power requirements between now and 1980, and to estimate how these needs will be met.

Table 1 shows the actual electrical energy requirements of REA borrowers in 1958, and the estimated requirements through 1980, arranged by the electric power supply areas established by the Federal Power Commission. The estimates of future requirements assume a uniform rate of increase in all areas.

The electrical demand equivalents of the power requirements shown in table 1 are contained in table 2.

Information we have on the types of generation supplying the energy used by REA borrowers is limited to REA-financed generating plants, which supply about 15 percent of the total energy requirements. At June 30, 1958, REA-financed generation was as follows:

Type of prime mover:	*Installed capacity (kilowatts) at June 30, 1958*
Steam	854, 750
Internal combustion	296, 166
Hydro	44, 569
Total	1, 195, 485

It is not possible to forecast with any degree of certainty the proportion of future power requirements of all REA borrowers which will be supplied by borrower-owned generating plants. The variables involved are too numerous.

On the assumption that borrower-owned generating plants continue to supply about 15 percent of borrowers' total energy requirements through 1980, the composition of this generation is estimated to be:

Type of prime mover:	*Estimated installed capacity (kilowatts) in 1980*
Steam	5, 500, 000
Internal combustion	400, 000
Hydro	100, 000
Total	6, 000, 000

The above estimate indicates that most of the additional capacity to be installed by REA borrowers will be steam generation. Most of these steamplants will be fired with fossil fuels. By 1980, generating from nuclear-fueled plants may account for 15 to 25 percent of the total installed steamplant capacity owned by REA borrowers.

Sincerely yours,

TRUE D. MORSE, *Acting Secretary.*

TABLE 1.—*Electrical energy requirements of REA borrowers by FPC power supply areas*

FPC area	Actual kilowatt hours (billions) 1958	Estimated kilowatt-hours (billions)			
		1965	1970	1975	1980
1	0. 6	1. 2	1. 9	2. 7	3. 8
2	1. 9	3. 9	5. 9	8. 5	12. 0
3	8. 2	16. 8	25. 3	36. 6	51. 6
4	3. 5	7. 3	10. 9	15. 8	22. 3
5	4. 2	8. 5	12. 8	18. 5	26. 2
6	2. 2	4. 5	6. 7	9. 7	13. 7
7	1. 5	3. 0	4. 5	6. 5	9. 1
8	. 2	. 4	. 6	. 9	1. 3
Total	22. 3	45. 6	68. 6	99. 2	140. 0

NOTE 1.—The above estimates assume annual load factors of 46 percent in 1958; 47 percent in 1965; 48 percent in 1970; 49 percent in 1975; and 50 percent in 1980.

NOTE 2.—On the assumption that REA borrower-owned generating plants continue to supply about 15 percent of borrowers' total energy requirements through 1980, their generating capacity will produce 21 billion kilowatt-hours of the total requirements of 140 billion kilowatt-hours shown in table 1. Approximately 6 million kilowatts installed capacity will be required, including capacity used for standby and peaking.

TABLE 2.—*Electrical demands of REA borrowers by FPC power supply areas*

FPC area	Estimated megawatt demands				
	1958	1965	1970	1975	1980
1	150	290	450	630	870
2	470	950	1, 400	1, 980	2, 740
3	2, 030	4, 090	6, 030	8, 530	11, 770
4	870	1, 770	2, 590	3, 680	5, 090
5	1, 040	2, 060	3, 040	4, 310	5, 980
6	550	1, 090	1, 590	2, 260	3, 130
7	370	730	1, 070	1, 510	2, 080
8	50	100	140	210	300
Total	5, 530	11, 080	16, 310	23, 110	31, 960

STAFF REPORT ON HYDROPOWER

DECEMBER 21, 1959.

JOSEPH L. FISHER,
Executive Director, Resources for the Future, Inc.,
Washington, D.C.

DEAR MR. FISHER: The Senate Select Committee on National Water Resources is interested in estimating future water use requirements for hydroelectric power generation. Our staff director informs me that Resources for the Future, Inc., has made an analysis of the future of hydroelectric power in the United States which will be a part of an overall study of "Energy in the American Economy, 1850–1975," and that he believes this analysis would be of great value to our committee.

As your overall study will not be published in time to be used by this committee, I am writing to ask if Resources for the Future would be willing to help us by making its analysis of the future hydroelectric power available to us for reproduction in a committee print, along with the reports on electric power which the committee is securing from other sources.

We would expect to give appropriate credit to Resources for the Future and the individual authors of the study if you are so kind as to make it available for this purpose.

I appreciate greatly the work which your foundation is doing for the committee in the field of water supply-demand relationships and I look forward with great interest to the receipt of your report on this subject.

With best wishes, I am,
Sincerely yours,

ROB'T S. KERR, *Chairman.*

RESOURCES FOR THE FUTURE, INC.,
Washington, D.C., January 7, 1960.

Hon. ROBERT S. KERR,
Select Committee on National Water Resources,
U.S. Senate, Washington, D.C.

DEAR SENATOR KERR: The analysis to which you refer in your letter of December 21 was made by Bruce C. Netschert, senior research associate in our energy and mineral resources program. It was prepared as a chapter on the future supply of hydroelectric power in our forthcoming book, "Energy in the American Economy, 1850–1975."

I am happy to know that this analysis is of interest and value to your committee; it is a pleasure to make the chapter available to you for inclusion in a committee print.

We have been pleased to work with the Select Committee on National Water Resources on the study of water demand-supply relationships, and we hope the report will be helpful.

Sincerely yours,

JOSEPH L. FISHER,
President and Executive Director.

THE FUTURE OF HYDROPOWER THROUGH 1975

By Bruce C. Netschert

[This study is a chapter from a larger work entitled "Energy in the American Economy, 1850–1975," a forthcoming publication of Resources for the Future, Inc.]

INTRODUCTION

The pace and extent of hydropower development depend in general on governmental policy decisions, the interest rate, regional growth in demand, the cost of competitive energy sources, the magnitude of unexploited hydro resources, and technological progress as it affects the exploitation of the hydropower potential. The emphasis of this study is on the resource and technological determinants; the others are considered where relevant.

If unexploited hydro resources are conceived to be finite, then, as an increasing proportion of the total is developed, the rate and extent of further development is more and more influenced by the magnitude of the remainder. Equally significant is the technology of the various aspects of hydropower development—dam and facility design and construction, turbine and generator design and operation, and the transmission of the generated power—that determine, in the last analysis, the economic feasibility of exploiting the remaining potential. To be sure, the feasibility of developing a specific site may depend, perhaps even chiefly, on its place in an integrated power system or in the multipurpose development of a stream basin or region; but such considerations for the individual sites are not practicable in this discussion, which deals with the national aggregate level.

Feasibility will also depend to a large extent on the consumptive uses of water and head (see below) which in a sense compete with hydropower. The withdrawal of water from a stream for irrigation and for industrial, commercial, and household use reduces the streamflow and/or head by some degree even if there is provision for return of the waste, since there is always some loss of water in use; thus the hydro potential represented by the streamflow is also reduced. The consumptive use of water can be expected to increase in the future, as it has in the past, through economic and population growth. The relation of this demand for water to future hydro availability is, however, a research project in itself, and cannot be attempted in this study. All that can be done here is to recognize that this is a limiting influence on hydropower availability that will manifest itself in an unmeasurable degree.

Accordingly, this study considers first the hydropower resources from which additions to capacity must come. The published estimates of future installed capacity in given years (that is, the total hydro generating capacity that will be in place in the given year) are then listed and the basis for each is described. There follows an examination of technology and its future prospects, as these may affect hydropower development. The various capacity estimates are evaluated as part of the conclusions of the study.

THE CONCEPT AND MEASUREMENT OF HYDROPOWER RESOURCES

Characteristics of hydropower

The subject of hydropower resources has been the province of engineers; the literature is thus technical, with a specialized vocabulary. The present discussion attempts to review current authoritative opinion while avoiding oversimplification and generalization. The following paragraphs constitute a brief review of the characteristics of hydropower and the peculiar problems of resource measurement they raise.

Hydropower potential is created by the flow of water between different elevations. (The difference in elevation is termed the "head.") The energy of the water is used to turn a waterwheel and is converted into electricity by a generator driven by the waterwheel. The capacity of an actual or potential hydropower installation is measured in kilowatts, and the energy produced, or producible, in kilowatt-hours.

The outstanding characteristic of the demand for electricity in a typical electric power system is its periodic variation. Daily and seasonally the demand rises to peaks which may be considerably greater than the average level. The ratio of the average load, or demand for kilowatts, over a designated period to the peakload occurring in that period is termed the "load factor." The significance of this relationship is that generating capacity must be sufficient to take care of the peakload, hence in excess of the average load. Further, excess capacity must be provided over peakload to allow for equipment outages necessitated by maintenance or breakdown.[1]

The ratio of the average load on the plant, for the period of time considered, to the aggregate rating of all the generating equipment installed in the plant is known as the "plant factor". The higher the average use of the plant capacity during a given period, the higher is the plant factor for that period.

Against these universal characteristics related to the demand for electricity and the plants which supply it are production characteristics peculiar to hydropower. The flow of the stream being utilized for hydropower commonly varies over both long and short periods, reflecting rainfall and runoff patterns. In the ideal stream these fluctations would correspond precisely to the desired variations in the output of its hydroplants. Differences between short-period fluctuations in streamflow and desired variations in plant output can be overcome through the use of a small reservoir to provide pondage for the plant; long-term regulation of flow can be provided through storage reservoirs. Unless a plant has storage it is termed a "run-of-river" plant, either with or without pondage. Under any of these conditions, however, both flow and head can normally be expected to vary.[2]

Nevertheless, there is at any site a minimum flow below which the stream can normally be expected not to fall. The power capability that this flow and the available head represent is termed the "continuous power" or "prime power" that can or could be produced at that site. The principal function of a storage reservoir for power purposes is usually to increase the minimum flow, hence the continuous power level.

The use of waterpower for electricity generation is further complicated if such use is part of a multipurpose development. If the stored water is also used for irrigation or maintenance of a navigation channel not all of it may be available for power, and the continuous power level that can be assigned to the associated hydro power facilities is thereby lowered. Similarly, the use of a reservoir for flood control may be incompatible with maximum power development, for a reservoir must be kept low in periods when floods may occur if it is to fulfill its flood control function, but this reduces the head available for power generation and may limit the amounts of water that can be stored for later use in power generation when natural streamflows are low. (Thus irrigation and navigation may also be in some degree incompatible with flood control.)

The rationale and methodology of estimating hydropower resources have received a good deal of attention in recent years, especially under the aegis of the World Power Conference. Interest has been stimulated in improving and standardizing concepts and measurement techniques. As a result there is currently coming into acceptance outside the United States a standard terminology in defining and measuring hydropower resources.[3]

The reason for the lack of enthusiasm for the subject in this country does not appear in the literature but is obviously related to the different energy position of this country from that of most other countries. The United States possesses abundant energy resources of other kinds, and there has not been a strong sense of urgency toward maximum exploitation of hydro resources. In other countries, where energy resources in general are scarce, or at least higher cost, the development of hydro resources does acquire urgency and leads to a high degree of interest in the identification and measurement of such hydro resources as remain undeveloped.

The starting point, conceptually, in the new hydro resource terminology is the natural environment within the geographic limits of the area or country considered. Since the physical basis of hydropower is a quantity of water descending a vertical distance, the maximum conceivable hydropower potential of a country is represented by the total quantity of water flowing in its streams, and the vertical distance it descends. This concept of total flow times head is the "theoretical hydroelectric potential."[4] It is defined in kilowatts for the period of a year as $\Sigma 9.81\, qh$, where q is the arithmetic mean flow (cubic meters per second) over a period of years, of yearly average natural flows at the midpoint of each watercourse, and h is the gross head (in meters), or the difference in elevation between the terminal points of the streams. In terms of annual energy output (potential kilowatt-hours) the definition is $\Sigma 85{,}848\, qh$, or kilowatts multiplied by 8,760, the number of hours in a year.[5]

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[1] Normally, excess capacity must be provided on a system basis. It would be taken into account for an individual plant only if the plant operates alone.

[2] Exceptional circumstances exist where natural storage is virtually unlimited, providing unusually constant streamflow, as at Niagara Falls and on the St. Lawrence River.

[3] See, for example, the various reports of and to the Economic Commission for Europe and the Economic Commission for Asia and the Far East, several of which are cited below.

This theoretical physical potential is, of course, forever unattainable. It assumes a high degree of equalization of seasonal flow (theoretically attainable through perfect storage facilities perfectly utilized but not necessary unless the load to be carried is absolutely uniform) and complete utilization of the flow (no competing uses or withdrawals of any kind); complete utilization of head; and 100 percent efficiency (i.e., complete conversion of the hydro energy into electricity) and—in terms of annual energy—100 percent utilization of the power capacity throughout the year.

Within this theoretical limit there is distinguished a concept termed the "technical potential." This is considered to represent the total hydro resources that can be developed with a given state of technology. The technical potential can be derived from gross potential by deducting losses of head in headraces, penstocks, etc., losses of flow due to alternative water uses, leakage past water-controlling apparatus and incomplete flow regulation because of imperfect storage; and, in terms of generated power, the losses due to turbine and generator inefficiency, and losses due to the fact that continuous operation throughout the year is not feasible.[6]

A second method of deriving the technical potential is the summation of the potential at all developed and identifiable undeveloped sites. There is, however, an abrupt conceptual jump from total flow and head along a stream or all streams to the technological limits on usable flow and head at specified generation sites. The technical inability to capture and utilize all of the energy available at a given site means, of course, that the technical potential at that site is less than the theoretical potential of the site. But in considering the theoretical and technical potentials in the aggregate—for a country, a region, a drainage basin, or even an individual stream—the technical will also be less than the theoretical for the additional reason that the total potential of all hydropower sites does not equal the total energy represented by qh for the country, region, etc., even allowing for equipment inefficiency. There will be instances where it is technologically infeasible to specify a powersite; the head may be to small to be usable, for example, or the geology or topography may be too unfavorable to cope with in considering the structures necessary for storage. Other reasons can be adduced.

The concept of technical potential has been criticized as being very unprecise on the grounds that it is too broad,[7] but it can also be criticized for for failure to specify the place of the economic element in the concept. In one sense the technological inability to make complete use of flow and head at a given site does not involve costs—the technological limits are not a matter of cost in that more expensive facilities or techniques would not increase significantly the technical potential as a percentage of the theoretical potential. In this sense, therefore, the technical potential at the level of the specific site disregards costs by taking them to the limit: regardless of cost, X kilowatts is all that is technically possible here. The same is true in general of the concept in the aggregate, although this cannot be stated categorically. The failure to identify sufficient sites to capture all the qh of a stream, etc., may be due in some part (how much is impossible to say) to implicit cost limitations. Geological and topographical and other disadvantages[8] could perhaps be overcome at some wholly extravagant cost. Hence in this sense the concept remains fuzzy, as Yevdjevic avers, unless the place of costs is noted. Costs are comprehended in the concept of technical potential, but are disregarded in the sense that they are not a limiting factor when the concept is correctly stated. In this discussion the term

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[4] Other concepts of the theoretical potential also exist, such as the "theoretical runoff potential" and the "theoretical rainfall potential," but these are irrelevant to the present discussion.

[5] Economic Commission for Europe, Committee on Electric Power, "Hydroelectric Potential in Europe and Its Gross, Technical and Economic Limits," United Nations, Geneva, May 1953, p. 51.

[6] Cf. ibid., pp. 61f; and A. J. Dilloway, "Assessment of Hydroelectric Potential in Regions Subject to Rapid Economic Development," Fifth World Power Conference, paper 47 B/3, p. 5.

[7] Cf. V. M. Yevdjevic, "Some Statistical Methods for Determining Water Power Resources," Fifth World Power Conference, paper 165 B/13, p. 6.

[8] Such as the cost of condemning a city that would be flooded by the reservoir.

"technical" is considered synonymous with "practicable," that is, it is a potential that may be feasible to realize some time in the future but such realization is not necessarily fully justifiable under current costs.

Within the technical potential there is a third conceptual limit for which costs are the limiting factor. The "economic potential" is thus the total hydro resources that can be developed with a given level of technology under given relative cost conditions. (For the purposes of this discussion, the capacity that would have a competitive margin over alternative energy sources.) Again, the proportion of the technical potential that is economic does not necessarily remain constant, but can change with changing economic circumstances. It is determined by such things as the interest rate, construction and operating costs, competitive energy prices, and so forth.

The concepts behind the foregoing terminology provide a useful scale of perspectives in a consideration of the undeveloped hydropower resources of a country.

The theoretical potential constitutes the environmental limit within which technology can be applied; the technical potential in turn is the limit of the resources that could be developed with a given level of technology under no cost limits, and the economic potential delimits the resources that can be developed according to prevailing costs and load conditions. There is thus a perspective suitable for whatever purpose is in mind. One may be interested in immediate additions to total generating capacity, or going up the scale in planning future additions that are, perhaps, not yet feasible, or one may even be speculating on new ways and means of harnessing potential hydropower. The appropriate perspective for each interest is available; the present study is interested in the entire scale.[9]

These concepts and the perspectives they afford are helpful despite the great difficulties of using the definitions as a basis for measurement. Although the definitions themselves are conceptually unambiguous, any attempt to quantify the technical and economic potentials involves the application of judgment in applying the limiting criteria. The definitions may remain objective but the measurement process must unavoidably be subjective to some degree. In addition, there is the difficulty of getting reasonable precision in the measurement of any of the potentials, since the most that can be expected is approximation (see below). Nevertheless, even rough figures obtained with the foregoing concepts in mind are more meaningful and useful than estimates of hydro resources with no systematic basis or criteria.[10] The concepts provide a framework within which necessary judgments can be applied consistently rather than haphazardly and upon which approximations can be systematically constructed.

It is least difficult to express the theoretical potential quantitatively, although even this requires the collection of large masses of data. One needs, in addition to fairly detailed topographic data for the entire country, hydrometeorological data in considerable detail over a sufficient period of years to provide statistical reliability, but available data are inadequate. This inadequacy of data—as with inadequate terminology—has led to a lively discussion in other countries of statistical procedures and devices for estimating the theoretical hydro potential of a country, and it is believed possible by many students of the subject to approximate the theoretical potential with a minimum amount of data using various statistical shortcuts.[11] It should be noted, however, that regardless of how an estimate of the theoretical hydro potential may be obtained, it makes no allowance for the loss of potential represented by existing and potential demand for consumptive uses.

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[9] The following quotation exemplifies the prevailing attitude in this country toward the terminology and concepts just outlined. Speaking of the theoretical potential, F. L. Weaver remarks: "This type of inventory obviously has limited usefulness. As an example, it is of little value to know that the lower Mississippi River has a power potential equivalent in capacity and generation to a very substantial proportion, possibly two-thirds, of that of all existing hydro plants in the country, if that potential cannot be developed physically or economically." ("Hydro Potentialities as Indicated by the Federal Power Commission," paper presented at 21st annual meeting, American Power Conference, Chicago, Apr. 1, 1959.) But to criticize the usefulness of the concept of a theoretical limit because that limit is unattainable is to miss the point entirely. The theoretical limit of thermodynamic efficiency in the steam cycle is equally unattainable. Like that limit, the theoretical hydro potential is useful as a reference point against which achievement can be measured.

[10] As the Economic Commission for Europe observes, periodic revisions of the technical potential "can be evaluated in terms of the theoretical upper limit as a datum. In areas where exploitable sites have not been surveyed, knowledge of gross upper limit also allows estimates of practical limits to be prepared" (op. cit., p. 4).

[11] For example, certain simplified assumptions can be made regarding the relation between mean head of the drainage area and specific runoff on the one hand and the size of the drainage area on the other hand, using the relation kw/km along the watercourses. (See T. L. Solotarjow, "Die Methodik der Berechnung von Wasserkraftvorräten," Paper 261 B/16, Fifth World Power Conference, op. cit.; see also Economic Commission for Europe, op. cit.; Dilloway, op. cit.; V. Felber, "Abflusskurven und Abflusskurvensysteme in der Gewasserkunde," Paper B/2, Fifth World Power Conference, op. cit.; A. Bernhard, "Methodische Fragen der Wasserkraftstatistik, erlaütert am Beispiel des osterreichischen Wasserkraftkatasters," Paper 39 B/1, ibid.; and Yevdjevic, op. cit.)

The measurement problem becomes more serious at the technical potential level. The losses due to equipment inefficiency can be averaged from current experience, summed, and subtracted from the theoretical potential. But a more meaningful and useful way to measure the technical level is to survey all potential hydropower sites to determine the capacity that would be practically installable at a given time. The question of just what is technically feasible can never be wholly settled. Such site-by-site surveys are, moreover, time-consuming and expensive, and if undertaken they are likely to understate the situation because they "tend always to stop at physical and cost limits which go little beyond expectations of use." [12]

Even more troublesome is the difficulty raised in obtaining an energy (kilowatt-hour) estimate as distinguished from a capacity (kilowatt) estimate. The technical potential in terms of energy is based on mean flow, but the installed or installable capacity bears no systematic relation to mean flow, being influenced rather by a variety of economic and physical considerations such as the range of flow conditions and the integration of the site into a power system. The best that can be done is to estimate the output in kilowatt-hours for all installed and installable [13] capacity and to divide by 8760 (the number of hours in a year) to get a continuous generation equivalent, termed "comparative capacity" by the Economic Commission for Europe, to compare with the constant (in the sense of unvarying) flow implied by the mean flow concept. This is probably the weakest element in the measurement of the hydro potentials.

The measurement problem becomes most acute at the level of the economic potential. Theoretically it should be possible to construct a cost schedule of all undeveloped hydro sites, based on the cost per installed kilowatt or kilowatt-hour output at each.

> Of sites found to be technically exploitable, some will be structurally unsound, requiring costly excavation and strengthening. Others may be topographically complex and need extensive diversions, costly barrages or other special modifications before their full potentialities can be realized. Very large low-head installations on navigable rivers can fall within this category.
>
> Again, a project may be difficult of access, far removed from any consumption center, or it may have to compete with others where a dual purpose would help to amortize power costs or where a cheap fuel supply holds greater attractions for baseload production.[14]

The traditional economic criterion for a hydropower installation was the cost of an equivalent block of power from thermal capacity, the cheapest alternative source. This was useful as long as a hydropower project could be assessed in terms of power only, but with the increasing emphasis in this country on multipurpose development a large part of the power aspect may be automatically incorporated in the overall project, in which instance the even more complex and imprecise technique of benefit-cost ratios may be used to determine whether the overall project is economic.[15]

Thus in practice the actual cost schedule [16] of potential hydropower projects is likely to be difficult to indicate even within wide limits, and there is the further difficulty of fitting specific increments under load curves. These difficulties led the President's Materials Policy Commission to conclude:

> There is no completely satisfactory measure of the remaining hydropower that could be developed * * * There are extreme variations in the probable capital and operating costs of generating electricity at different sites. Even where costs are similar the economic possibilities of development will vary according to the differences in the prospects for power demand and the conditions of supply in the particular area. Moreover, the potential

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[12] Economic Commission for Europe, op. cit., p. 1. This is stated more fully by Davis: "With a caution customary among engineers, statistics pertaining to some of the lesser known (and yet possibly favorable) sites are frequently disregarded, until such time as the necessary runoff, topographic and dam foundation conditions have actually been subjected to exhaustive survey. * * * Where a high dam structure is envisaged, or considerable tunnelling is involved, the possibility of using new and improved techniques cannot always be anticipated. Often left out of account until the need arises, are the additional capacities possible through the greater use of storage and stream regulation. River diversions from one watershed to another may also result, sometimes quite unexpectedly, in new freedoms for increased hydropower generation. Thus potentials such as those recently established at Kitimat or envisaged for the Columbia or Fraser River systems had for years been disregarded either as unproven or visionary, *if not entirely out of the question*" (Italics added) (J. Davis, "Canadian Energy Prospects," Royal Commission on Canada's Economic Prospects, Ottawa, 1957, pp. 219f).

[13] Again, it is difficult to delineate the cost element precisely. If costs were totally disregarded, it would generally be possible to install sufficient capacity at each site to utilize even maximum flows. "Practically installable" should be understood here.

[14] Dilloway, op. cit., p. 5.

[15] Cf. Doland, op. cit., pp. 172f. Indeed, the determination of whether the individual aspects of a multiple purpose project are economic is probably even more difficult.

[16] Using this term in the economist's sense, i.e., a schedule of the cumulative capacity that would be available at each successive cost level, as in a "supply schedule."

level of power that can be generated and the costs will vary widely for a single site according to how the whole river basin is developed. A river with a wide seasonal fluctuation in water flow will have a much greater year-round power potential if storage reservoirs are built upstream to even out seasonal fluctuations at power sites downstream.[17]

Judgment as to the efficacy of quantifying hydro potentials for this country is deferred in this study until the concluding section. In the following section the current estimates of the hydro resources of the United States (48-State basis) are examined against the background of the concepts and definitions set forth above.

ESTIMATES OF HYDROPOWER POTENTIAL IN THE UNITED STATES

Description of the estimates

There are two Government estimates of U.S. hydropower potential, one by the U.S. Geological Survey and one by the Federal Power Commission. The estimates considered here are the latest in a series of periodic revisions published by the two agencies. (The Survey has now ceased its activity in this field.)

The Geological Survey figures consist of estimates, over a range of assumptions, of potential power, defined as that "estimated technically capable of being developed, economic infeasibility notwithstanding." [18] The definition is intended to include developed as well as undeveloped power. The estimates in Young's paper cover capacity available 50 percent and 90 percent of the time, with storage at known, large reservoir sites, both developed and undeveloped; and capacity at mean flow (since time is not a parameter for mean flow, the estimate is the same with existing as with projected storage).[19] All of the estimates assume 100 percent efficiency and gross head. On this basis the potential is:

	Kilowatts
Available 90 percent of the time	48, 479, 000
Available 50 percent of the time	63, 873, 000
Based on mean flow	86, 174, 000

The Federal Power Commission describes the basis of its estimates as follows:

> The Commission estimates and assembles data on the undeveloped hydroelectric power resources of the principal river basins of the country. This is done by making use of data obtained during the course of comprehensive river basin surveys, made either in connection with the Commission's hydroelectric power project licensing work or in cooperation with other Federal agencies, and by using information obtained from investigations made by other Federal agencies and by other interests, public and private. The Commission's estimates are based on the rated capacity of generators that normally would be installed at the power sites, assuming reasonable regulation of flow by storage. Allowance is made for depletions by irrigation and other consumptive use, and it is assumed that each site will be developed to achieve, in conjunction with the development of other sites, the best overall development of the water resources of the river basin for power and other multiple uses.[20]

On this basis, with data as of January 1, 1958, the latest of the Commission's periodic estimates of the hydroelectric power resources of the United States is: [21]

	Kilowatts
Developed and installed capacity (140.7 billion kilowatt-hours)	27, 854, 000
Estimated undeveloped capacity (369.1 billion kilowatt-hours)	90, 242, 000
Total (509.8 billion kilowatt-hours)	118, 096, 000

In addition to the Government estimates just described, many figures for the hydropower potential of the United States may be found in the literature. Most figures presented by individual writers cite one or the other of these Government agencies as the source reference. The estimates described above are thus the only estimates of hydropower potential derived from original statistics, and the figures given by individuals are, with a few exceptions, ignored in this study.[22]

The exceptions are a few estimates, presented without source references, that are highly misleading. Because they appear in authoritative surroundings it is desirable to indicate specifically in what respect they are in error. Harrison Brown, for example, uses a horsepower figure equivalent to 26.1 million kilowatts as the generating capacity, based upon ordinary minimum flow, that would be made available by "full development of potential hydroelectric sites in the United States." [23] This can be taken as generally equivalent to the Geological Survey's estimate of the potential with existing flow available 95 percent of the time, or 27.1 million kilowatts. Under the conditions specified, Brown's figure describes the limit of continuous hydropower as seen at that time, but in no sense measures the "full development" of the hydropower potential. Indeed, installed capacity already exceeds that level.

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[17] President's Materials Policy Commission, "Resources for Freedom," vol. 1, Washington, Government Printing Office, 1952, p. 118.

[18] L. L. Young, "Developed and Potential Waterpower of the United States and Other Countries of the World," December 1954 (U.S. Geological Survey Circular 367), Washington, 1955, p. 2.

[19] Ibid., passim. Young also presents estimates of the potential "under existing conditions"; that is, existing storage facilities are taken into account but no allowance is made for reservoirs that could be established in the future. These estimates are not considered relevant to the present discussion.

[20] Federal Power Commission, "Hydroelectric Power Resources of the United States: Developed and Undeveloped, 1957" (Washington: 1958), pp. 18f.

[21] Federal Power Commission, "38th Annual Report" (Washington: 1959), p. 39.

[22] One estimate not dealt with herein is quasi-official in that it is based on governmental data but appears in an unofficial paper. (W. B. Langbein, An American Survey, "Water Power," November-December 1950.) Langbein's estimates are based on Geological Survey data since superseded by the data that form the basis of the agency's official estimates in the 1955 publication described above.

Other authors use a different figure for the hydropower potential but similarly misstate the situation. Ayres and Scarlott proclaim: "* * * the amount of electric power that can be ultimately produced from waterfalls is definitely limited to about 50 million kilowatts * * *,"[24] and Pigott avers that "hydropower cannot exceed 50 million kilowatts capacity—that's all there is." [25] These unqualified statements correspond to the Survey estimate of 48.5 million kilowatts as the potential hydropower available 90 percent of the time with storage. This is also a measure of continuous power possibilities, but again, to suggest any figure of this kind as a flat upper limit to hydropower possibilities without any attempt to consider its relation to the theoretical potential is at the least misleading.

Critique of the Government estimates

The purpose of the Geological Survey estimates by Young appears to be merely to make available for general use figures that were a byproduct of other work. The specific function of the Survey with respect to hydro potential is the classification of public lands for hydropower purposes—the Survey must identify potential powersites involving such lands as the basis for deciding whether the land should be withdrawn from other use because it may one day be flooded by a storage reservoir. The streamflow data developed by the Survey for this purpose (as well as for flood information) are detailed and comprehensive and are collected on a consistent basis, but where necessary they were supplemented from other sources to give the totals presented.

Young calls his results the potential waterpower of this country, but no thought seems to have been given to what their true meaning and significance might be, such as the implications of the gross head and 100 percent efficiency assumptions. As will be seen shortly, the estimates are not a valid measure of the potential waterpower of the United States. No indication is given, moreover, of what the Survey thinks of the relative usefulness and validity of the figures with different parametric values,[26] nor is there any indication of the coverage provided by the sites which undoubtedly will be developed at some future time but would not individually add materially to the potential of the stream or the country as a whole.[27] Even if the judgment of the Survey on the significance of the deliberate exclusion is accepted, it is reasonable to expect some statement of the adequacy of coverage, such as is provided in the Survey's estimates of coal resources, for example.

The Federal Power Commission comments on its estimates as follows:

> The estimates of undeveloped water power include projects on which economic feasibility has been demonstrated, as well as projects at sites where physical conditions indicate engineering feasibility and promise at some time of economic feasibility. The estimates with respect to the latter class of projects are subject to revision either by increase or decrease as additional information becomes available concerning streamflow, reservoir sites, costs, and other pertinent factors.
>
> The undeveloped hydroelectric power picture is constantly changing as new projects are constructed, and as continuing studies by Federal, State and local public, and private interests uncover new potential projects, or their investigations demonstrate the desirability of modifications of older plans. Hence, estimates of undeveloped hydroelectric power must be revised from time to time as new studies are made and additional information is obtained. Although some of these potential projects may, upon detailed investigation, be found infeasible and impracticable of development from physical, or economic, or other standpoints, the estimates taken in the aggregate serve to indicate, from a long-range view, the overall waterpower potential of the United States and the waterpower resources available for possible future development.[28]

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[23] H. Brown, "The Challenge of Man's Future," Viking, New York, 1954, p. 171.

[24] E. Ayres and C. A. Scarlott, "Energy Sources—The Wealth of the World," McGraw-Hill, New York, 1952, p. 104.

[25] R. J. S. Pigott, "Fuel and Power Sources If and When Oil Fails," Petroleum Refiner, vol. 28, No. 2, February 1949, p. 88.

[26] The use of 95 percent availability with existing flow and 90 percent with full storage is, for example, unexplained. It does not correspond with usage elsewhere. (Cf. J. J. Doland, "Hydro Power Engineering," New York: Ronald, 1954, p. 48.)

[27] Young, idem.

[28] Federal Power Commission, "Hydroelectric Power Resources of the United States: Developed and Undeveloped, 1957," p. 19.

Although this emphasizes the ephemeral nature of the total figure representing the hydroelectric power resources of the United States as estimated by the Commission, it fails to indicate that the estimate is the summation of a series of data from unrelated reports from various sources originally made for a variety of purposes. The data collected range from detailed specifications of the basis for an installed capacity estimate to unsubstantiated guesses. The installed capacity figures for undeveloped hydro have been taken by the Commission as given in the collected data, except for revision to accord with later information, and have no consistent basis. The figure also excludes small powersites of less than 2,500 kilowatt potential. The total potential of such sites in the data available to the FPC amounts to less than 5 percent of the total estimate, but it is not known what the total potential of all such sites would be The Commission, moreover, does not accompany its estimates with a statement of the exclusion. The reader is left to infer that the coverage is complete. In any event, the FPC estimate is not, as Weaver describes it, "a summarization of resources available for possible development similar, for example, to summarizes of the amount of coal or iron ore available in the country." [29] A "summarization of the resources available for development" (with no indication of feasibility) would be the theoretical potential.

How can the estimates of the United States hydro potential be described in the terminology adopted herein? It is impossible to assign the estimates to any of the three categories without qualification. There is no estimate that corresponds to the concept of theoretical potential, since there has been no all-inclusive survey of flow and head for the drainage basins of the United States (although comprehensive data probably exist in the files of the Government agencies). The closest approach to the theoretical potential is Young's mean flow figure, since it is accompanied by gross head and 100 percent efficiency assumptions. But it is the sum of identified sites, not a flow-head product, hence conceptually it falls short of the theoretical potential. On the other hand, the same estimate is taken to the technological limit (see quotation above, p. 68), which is the basis of the technical potential concept, but even though the measurement is on a site-by-site basis, the coverage is incomplete, hence in this respect it falls short of being a measurement of technical potential. Conceptually, Young's mean flow estimate is between the two potentials, making the flow-head-efficiency assumptions of the theoretical potential and the practicability assumption of the technical potential.

The Federal Power Commission's estimates pertain to installed capacity and kilowatt-hour output, and can be related to the several potentials only through conversion to "comparative capacity," with all the shortcomings this brings with it (see above, p. 67). Aside from the measurement problem, however, it is conceptually equivalent to none of the potentials. It specifically goes beyond the current economic limit; at the same time, its coverage is also incomplete.

In addition to assessing the meaning and significance of the two resource estimates in the perspective of the "potentials" terminology, it is useful to consider their comparability, especially since Young raises the question. It is evident that they cannot be directly compared: the FPC estimates are in terms of the capacity that has been or could be installed at each site; Young's estimates refer to the power that would be available when the streamflow is utilized steadily at the streamflow rate which occurs with the frequency stated. Young also assumes gross head and 100 percent efficiency, although the result is in each instance something less than present plus probable installed capacity. How, then, can the two sets of estimates be equated?

Young attempts an explicit comparison of these two sets of estimates (using the figures in the FPC report for 1953) as follows:

> By adding the Federal Power Commission estimates of average annual output in kilowatt-hours for developed and potential power and converting that total to a continuous [power] equivalent, it will be seen that their estimate of the total waterpower resources of the United States is near the

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[29] Weaver, op. cit. In Canada, by contrast, there is greater awareness of the incompleteness of the equivalent official estimates:

"With respect to hydraulic head, the figures * * * are based upon the actual drop, or feasible concentration of head, which has been measured or at least carefully estimated at existing falls, rapids, and known powersites; no consideration has been given to possible economic concentrations of head on rivers and stream of gradual gradient, except at those locations where the feasible head has been definitely established by field investigations. Many unrecorded powersites exist on rivers and streams throughout the country, particularly in the less explored northerly districts, but these cannot be included in the tabulation until more detailed survey work has been made. Thus, regarding both the total number of sites and the possible head at each site, the listed figures of available power represent only the *minimum water power possibilities of Canada*" (Department of Northern Affairs and National Resources, Water Resources Branch, Water Power Resources of Canada (bull. No. 2641) Ottawa, Mar. 16, 1959, p. 3). [Italics in original.]

> 56,060,000 kilowatts [the Young estimate of potential under existing conditions] * * * available 50 percent of the time and that it is at the midpoint between the potential power estimated to be available 90 percent of the time and 50 percent of the time with development of known storage sites * * *.[30]

Young, in other words, converts the FPC estimates of potential energy output of their estimated capacity into the equivalent power corresponding to that energy produced at a continuous rate. The arithmetic is as follows, using the figures in the FPC estimates of 1953:

	Million kilowatt-hours
FPC estimate, average annual generation by present hydro capacity	112, 479
FPC estimate, average annual generation by undeveloped hydro capacity	378, 508
Total	490, 987

NOTE.—490,987 divided by 8,760 (hours in a year) equals 56,048,000 kilowatts (continuous capacity equivalent).

He compares this figure with his own estimate of 56,060,000 kilowatts available 50 percent of the time with "existing flow," and the 56,311,000 kilowatts he obtains by averaging his 90 and 50 percent availability potentials (with storage). The coincidence of the figures is satisfying, but the existing flow assumption in his own figure is not the condition assumed by the FPC, as is evident from the description of its estimates quoted above. Nothing is adduced to show that the results are anything more than mere coincidence or that the arithmetic procedure has any real meaning.

The two sets of estimates can also be compared on another basis that has been used in the literature. A Canadian study observes that installed capacity and streamflow capacity estimates can be compared by following the usual practice of industry of taking the commercially available capacity to be approximately one-third greater than consistent with the conditions of ordinary 6 months' flow" (i.e., flow available 50 percent of the time).[31]

Applying this to Young's estimates yields an implied installed capacity figure of 85.2 million kilowatts with storage. The 1953 FPC figure of 109.5 million kilowatts is 29 percent greater than this result. Thus, in this instance either the rule of thumb is inapplicable or the estimates are "wrong."

Young states that the FPC and his estimates "are in essential agreement" [32] but, although they are not necessarily inconsistent or mutually contradictory, they simply cannot be compared, as figures, because of their very different bases. Any attempt to do so is mere arithmetical exercise. Young's figures purport to be for technically feasible projects, even though they may be uneconomic, but the FPC figures are for sites which promise economic feasibility. And still again, the Young estimates assume gross head and 100 percent efficiency, whereas the FPC figures reflect net head and attainable efficiencies.

ESTIMATES OF FUTURE HYDROPOWER CAPACITY IN THE UNITED STATES

In this section the published estimates of future hydropower capacity in the United States are described and compared so as to contribute to the basis for an independent judgment of the likely level of installed hydropower capacity in 1975. The estimates vary in completeness, in manner of expression, and in the year to which they refer. Ideally, they should be wholly comparable, but it was considered possible to reduce them to a common basis only in manner of expression—all estimates are listed as installed capacity of hydro facilities. Where estimates were incomplete and referred only to certain sectors of hydro capacity (such as federally owned, or interconnected systems only) it was not possible to impute to the estimates the unspecified remainder. On the other hand, the small place of industrial hydro in the total (less than 2.5 percent at present) allows figures that exclude this sector to be taken as generally equivalent to the total hydro capacity.

Rather than do violence to implicit assumptions in those estimates for years other than 1975, it was considered preferable to list each estimate for the year stated rather than to attempt conversion by interpolation or extrapolation to the common year 1975. Finally, in several instances the assumptions and definitions on which the estimates were based were not given in the respective sources. Where possible, these unstated bases were inferred. The estimates are presented in table I in approximately the chronological order in which they were published.

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[30] Young, op. cit., pp. 13f.

[31] J. Davis, "Canadian Energy Prospects" (Ottawa: Royal Commission on Canada's Economic Prospects, 1957), p. 219. It should be noted that this ratio looks low in the light of the situation described below on p. 85.

[32] Young, op. cit., p. 13.

TABLE I. *Estimates of future U.S. hydropower capacity*

Source and date (1)	Year for which estimate made (2)	Estimated capacity (thousand kilowatts) (3)	Remarks (4)	Estimate ÷ base year capacity, ×100 (5)		Implied average annual growth rate (percent) (6)	Implied average annual growth rate, 1961 to projected year ¹ (percent) (7)	Estimate as percent of hydro potential (FPC, January 1958) (8)
(a) Corps of Engineers-FPC (1948)	1968-73	59,540	Federal capacity only	(1947)	1,295	13.0-10.4	21.1-11.8	50
(b) Anonymous (1950)	1965	24,100	do.	(1949)	417	9.3	11.5	20
(c) PWRPC (1950)	1970	41,500	Total capacity	(1949)	235	4.1	1.0	35
(d) Anonymous (1951)	1975	39,700	4 percent of total energy supply.	(1951)	200	2.9	.3	34
(e) PMPC (1952)	1975	33,000-57,750	See text	(1950)	200-350	2.8- 5.1	(*)- 3.0	28-49
	1975	49,500			300	4.5	1.9	42
	1975	60,000	Total capacity	(1950)	321	4.8	3.3	51
(f) Bureau of Reclamation (1954)	1975	37,723	Federal capacity only	(1954)	370	6.4	6.5	32
(g) Monteith (1954)	1963	31,500	Total capacity	(1953)	137	3.2	(*)	27
(h) Cisler (1954)	1965	36,000	18 percent of interconnected systems total.	(1953)	163	4.2	(*)	30
(i) Cisler (1954)	1975	42,800-54,200	Interconnected systems only.	(1953)	194-246	3.1- 4.2	1.0- 2.7	36-46
(j) Sporn (1954)	1978	41,000	10 percent of total generating capacity.	(1953)	178	2.3	.5	35
(k) Mayer (1954)	1975	56,000	Total capacity	(1954)	231	4.1	2.8	47
(l) Mullendore (1955)	1975	50,000	Total capacity	(1954)	206	3.5	2.0	42
(m) General Electric (1955)	1975	35,000	Total capacity?	(1955)	136	1.5	(*)	30
	1980	44,000	9 percent of total generating capacity.	(1955)	171	2.2	.8	37
(n) Coal Age (1955)	1965	50,000	Total capacity?	(1955)	191	6.9	7.2	42
	1970	60,000			233	5.8	5.2	51
	1975	70,000			272	5.1	4.5	59
	1980	80,000			311	4.6	4.0	67
(o) McKinney Report (1956)	1965	27,700-28,000	Lower figures excluding industrial.	(1954)	119-115	1.6- 1.3	(*)-(*)	23-24
	1970	30,200-31,700			130-131	1.6- 1.7	(*)-(*)	26-27
	1975	32,600-40,600			140-167	1.6- 2.5	(*)- .5	28-34
	1980	35,200-52,900			152-218	1.6- 3.0	(*)- 1.8	30-45
(p) Sporn (1956)	1975	48,000	Total capacity	(1955)	186	3.1	1.7	41
(q) Ebasco (1956)	1970	55,500	18 percent of total utilities (excluding industrial).	(1955)	223	5.5	4.6	47
(r) FPC (1959)	1965	40,700	Total capacity	(1958)	137	4.4	2.4	34
	1970	45,700			152	3.5	2.1	39
	1975	51,700			172	3.2	2.2	44
	1980	57,700			192	3.0	2.2	49
(s) Electrical World (1959)	1975	50,740	Excluding industrial	(1958)	174	3.3	2.2	43

¹ See text, footnote 43. Asterisk (*) means the projection is less than indicated 1961 capacity.

TABLE I. SOURCES

(a) Public Utilities Fortnightly, vol. 42, No. 12 (Dec. 2, 1948), pp. 801-805.

(b) Electrical World, May 22, 1950, p. 109.

(c) President's Water Resources Policy Commission (PWRPC), "A Water Policy for the American People," vol. 1 (Washington, D.C.: U.S. Government Printing Office, 1950), p. 239.

(d) Mechanization, vol. XV, No. 11 (November 1951), pp. 89-100.

(e) President's Materials Policy Commission (PMPC), "Resources for Freedom," vols. I-V (Washington, D.C.: U.S. Government Printing Office, 1952), passim.

(f) Bureau of Reclamation, "Summary of Inventory of Future Development of Federally Identified Hydroelectric Power Sites in the United States," unpublished staff study, Jan. 8, 1954.

(g) A. C. Monteith, "Future Energy Sources," Proceedings of the American Power Conference, 16th annual meeting, vol. XVI, 1954 (Chicago, Illinois Institute of Technology), p. 41.

(h) W. L. Cisler, "Atomic Energy and its Industrial Applications," address to 1954 Coal Convention, American Mining Congress, Cincinnati, Ohio, May 3-5, 1954.

(i) W. L. Cisler, "Looking Ahead to the Last Quarter of the First Century of Electric Power in the United States," Bulletin, Edison Electric Institute, vol. 22, No. 6 (June 1954), p. 202.

(j) P. Sporn, "Electric Power Demand and Supply in the United States and the Role of Research in the Quarter-Century Ahead," proceedings, Institution of Electrical Engineers, vol. 101, pt. II, No. 82 (August 1954), p. 390.

(k) K. M. Mayer, "A Study of the Economic Potential of Nuclear Energy in the U.S. Power Industry," unpublished doctoral dissertation, New York University, 1954.

(l) W. C. Mullendore, "Hydroelectric Power," Bulletin, Edison Electric Institute, vol. 23, No. 6 (June 1955), p. 171.

(m) Public Utilities Fortnightly, vol. 56, No. 5 (Sept. 1, 1955), pp. 333ff.

(n) Coal Age, November 1955, p. 57.

(o) Panel on the Impact of the Peaceful Uses of Atomic Energy, "Peaceful Uses of Atomic Energy," vol. 2, report to the Joint Committee on Atomic Energy (Washington, D.C., U.S. Government Printing Office, January 1956), pp. 24-30.

(p) P. Sporn, "Sources of Energy for Electric Generation in the Two Decades Ahead," address to American Mining Congress, Cincinnati, May 7, 1956.

(q) Public Utilities Fortnightly, vol. 58, No. 11 (Nov. 22, 1956), p. 850.

(r) Federal Power Commission, press release No. 10,480, June 17, 1959.

(s) Electrical World, Sept. 14, 1959, p. 110.

The Corps of Engineers-Federal Power Commission estimate of 1948 represents the hydrocapacity considered at that time feasible and economic for Federal development during the following 20 to 25 years. It is thus not a true estimate of what installed capacity is likely to be in the future, but is the planned total of Federal development at that time, based on authorized projects, reports to Congress and plans in the course of preparation. Nevertheless, as an estimate of what could be installed it is considered here to be comparable with the other estimates of table I.

The anonymous estimate of 1950 is given without any stated basis. The estimate of the President's Water Resources Policy Commission is related to an FPC estimate of total installed capacity of 160 million kilowatts to meet energy requirements in 1970, which the Commission cites in concluding that—

> if present practices based on the most economical use of water power are followed, this will mean the development

> of about 25 million kilowatts additional hydroelectric power.[33]

The anonymous estimate of 1951 forecasts a doubling of 1951 capacity by 1975, based on the assumption that hydro would maintain its position in the total energy pattern at that time (i.e., about 4 percent of total supply) while the total energy output doubled.

The several estimates listed for the President's Materials Policy Commission have a varied basis. The figure of 60 million kilowatts appears in a chart on page 119 of volume I of the Commission's report. It is nowhere mentioned in the text of volume I, where the discussion of future hydro capacity is in much broader terms:

> Opinions differ widely as to how much of the undeveloped potential it would be economical to establish before 1975, using either a single or multipurpose approach as appropriate. It is quite possible, however, that our supply of hydroelectric energy could economically be doubled and conceivably be increased to 350 percent of 1950 levels. Further study of each river basin and individual site would be necessary for a more exact appraisal.[34]

In the paragraph preceding the quotation the report cites an FPC estimate of 16.5 million kilowatts installed hydro capacity as of the beginning of 1950, although this excludes plants of 2,500 kilowatts or less. Using the two- and three-and-one-half-fold increases mentioned by the PMPC, this would mean a range of 33 million to 57.75 million kilowatts installed hydro capacity by 1975.

A staff study in the PMPC report, however, makes the following statement:

> * * * it is clearly feasible, within 10 to 15 years, to double the installed hydro capacity over the early 1950 level. In addition, there would remain other sites that probably could be economically developed before 1975. An output of hydroelectric energy on the order of three times the 1950 level might be achievable by 1975.[35]

On the same basis this would mean a capacity of 49.5 million kilowatts by 1975. The chart thus uses a higher point than the range discussed by the Commission.

The Bureau of Reclamation figure is taken from a table prepared by the Bureau in answer to a request by the Atomic Energy Commission for a forecast of the schedule of Federal hydro development through 1975. It is based on an inventory of federally identified powersites and an estimated schedule of their development.

The forecast by Montieth, an official in the electrical equipment industry, has no accompanying basis beyond the statement that hydro will "diminish in relative importance in the next 10 to 20 years." [36]

The first of the Cisler estimates is an unelaborated statement that hydrocapacity will amount to 36 million kilowatts in 1965, or 18 percent of the total capacity of interconnected power systems. The second Cisler estimate is derived from the following statement:

> It is almost certain that thermal generating units will constitute upwards of 90 percent of the generating capacity to be installed in the next quarter century. This is because practically all the economic hydro sites have been developed in areas reasonably close to the heavy population centers, particularly in the eastern part of the country.[37]

Cisler listed actual and scheduled additions to hydro capacity from 1950 through 1955, and estimated maximum and minimum required additions to total generating capacity from 1955 to 1975. The figures imputed to Cisler in table I were derived by taking the hydro additions together with 10 percent of the subsequent total additions, and adding these to the FPC figure for installed utility hydro capacity at the end of 1949 (16.7 million kilowatts). The use of 10 percent means that the resulting figures are upper limits in the light of the quotation above.

The Sporn estimate is likewise an upper limit, with a very similar basis. Sporn believes that "waterpower may have difficulty in accounting for as much as 10 percent" of the total capacity in 1978, which he projects as 410 million kilowatts.[38]

Mayer's estimate is based on the Bureau of Reclamation figures (see above) plus an assumption that future private hydro expansion will be at the rate of roughly 10 percent of Federal hydro expansion. This is on the basis of all current and announced hydro construction as of 1952.

The Mullendore estimate states that hydroelectric capacity "is expected to increase * * * to a maximum of 50 million kilowatts in 1975."[39] The use of the term "maximum" is somewhat ambiguous. It is probable that Mullendore believes that 50 million kilowatts is as high as hydro capacity is likely to get by 1975.

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[33] President's Water Resources Policy Commission, "A Water Policy for the American People," Government Printing Office, Washington, 1950, vol. I, p. 239.

[34] President's Materials Policy Commission, "Resources for Freedom," Government Printing Office, Washington, 1952, vol. I, p. 119.

[35] Ibid., vol. III, p. 38.

[36] A. C. Montieth, "Future Energy Sources," proceedings, American Power Conference, vol. XVI, 1954, p. 41.

[37] W. L. Cisler, "Looking Ahead to the Last Quarter of the First Century of Electric Power in the United States," Bulletin, Edison Electric Institute, vol. 22, No. 6, June 1954, p. 202.

[38] P. Sporn, "Electric Power Demand and Supply in the United States and the Role of Research in the Quarter Century Ahead," proceedings, Institution of Electrical Engineers, vol. 101, pt. II, No. 82, August 1954, p. 390.

The General Electric figures are taken from a published summary of an unpublished report by that company on the future of nuclear power. While focusing on the place of nuclear power in 1980 the report specifies a total of 44 million kilowatts of hydrocapacity among total generating capacity in that year. An accompanying chart shows a projection of 35 million kilowatts hydro capacity to 1975. No basis for these estimates is presented.

The Coal Age estimates are accompanied only by the information that they are based on those of General Electric, described in the preceding paragraph and of Electrical World (see below).

The figures labeled "McKinney Report" are derived from a section in volume 2 of that report entitled "A Forecast of the Growth of Nuclear Fueled Electric Generating Capacity." Here estimates are given for total, thermal, and nuclear generating capacity at 5-year intervals through 1980. For table I hydro capacity was obtained as a residual. Although the primary purpose of these estimates was to estimate the growth of nuclear capacity, the derived hydro figure is a valid imputation, since the report states that "the growth of hydroelectric generating capacity is assumed unaffected by nuclear plants."[40]

The Sporn estimate of 1956 is given as follows:

> My own projections make me think that we shall have about 48 million kilowatts of installed hydro by 1975 * * *. This would mean that two decades from now slightly over one-eighth will be hydro * * *.[41]

The Ebasco estimate represents the judgment of that firm based on an evaluation of other estimates and on such basic information as was available. The chart on which the estimate appears was not accompanied by any explanatory statements, nor is any such statement available elsewhere.

The Federal Power Commission serial estimates are derived, in the Commission's words, from—

> considerable information with respect to potential hydroelectric projects, hydroelectric construction work now in progress, and plans of both Government agencies and private industry for developing power at the numerous river sites that have been studied * * * a careful analysis was made of such information in projecting hydroelectric generating capacity.[42]

The Electrical World estimate is based on the latest in that magazine's annual series of electrical industry forecasts. Yearly additions to hydrocapacity are given through 1962, and for the 1963–75 are assumed to be at a constant rate. The sum of these additions was here added to the existing hydro capacity (excluding industrial) as of the end of 1958 to obtain the figure listed in table I. No attempt is made here to estimate retirement of obsolescent capacity.

The foregoing estimates have been reduced to common bases in columns 5, 6, and 7 of table I. In column 5 each estimate is given as a percentage of its respective base year. Column 6 lists the implied average annual growth rate during the period from the base year to the estimated year. Column 7 lists the implied average annual growth rate during the period from 1961 to the estimated year; the 1961 level of capacity was obtained by adding to the level as of the end of 1958 the additions planned during 1959, 1960 and 1961, as listed in the February 23, 1959, issue of Electrical World.[43]

Columns (f) and (g) reveal a wide range in implied rates of growth, with the estimates for Federal capacity alone implying noticeably higher growth rates than all but one of those for total hydropower development. Both these features can be explained by the difference in past growth rates of Federal and non-Federal hydro and the manner in which future Federal development is viewed. The growth rates of the past and the immediate future are compared in table II, which demonstrates that an almost explosive development of Federal hydro has in the past outweighed the modest pace of non-Federal development to yield the 4–5 percent rate that characterized total hydro development. For the next few years this relationship will, however, be reversed, with a dramatic increase in the rate of non-Federal development outweighing an equally significant decline in the Federal growth rate for a net increase in the pace of total hydro development. It is evident, moreover, that almost all of the estimates of future total hydro capacity in table I imply a reduction from the current growth rate of total hydro capacity. The average of all the implied growth rates for total hydro capacity after 1961 in the estimates for the year 1975 is 2 percent per year.

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[39] W. C. Mullendore, "Hydroelectric Power," Bulletin, Edison Electric Institute, vol. 23, No. 6, June 1955, p. 171.

[40] Panel on the Impact of the Peaceful Uses of Atomic Energy, "Peaceful Uses of Atomic Energy," report to the Joint Committee on Atomic Energy, Government Printing Office, Washington, vol. 2, p. 9.

[41] I am assured (personal communication) that this estimate is, in fact, independently derived, and not the average of two Government bureau estimates cited by Sporn, as suggested by Oldacre. (M. S. Oldacre, "Energy Supplies for the Future," Industrial Development, March 1957, p. 8.) The two other estimates referred to by Sporn are (*a*) an unpublished Federal Power Commission estimate of 55 million kilowatts made in 1956, and (*b*) a figure of 39 million kilowatts for 1975 attributed to the Department of the Interior. This is derived from a figure given on p. 74 of vol. 2 of the McKinney report, contained in a report by the Department to the McKinney Panel. The figure is given in British thermal units, without any accompanying specific conversion factors for working back to kilowatt-hours and installed hydrocapacity. Sporn used his own conversion factors, which may or may not correspond to those used by the Department. Because of the absence of specified conversion factors, the Interior figure is not considered in this study.

[42] FPC, "Electric Power Requirements and Supply of the United States by Regions, Present and Future to 1980," FPC P-31, April 1958, p. 3.

[43] Total installed utility hydro capacity as of the end of 1958 was 29,363,000 kilowatts, according to Electrical World, of which 13,663,000 was Federal. To this must be added 700,000 kilowatts of industrial capacity. The planned additions, 1959 through 1961, listed by Electrical World, total 7,810,400 kilowatts, of which 1,934,500 are Federal.

TABLE II.—*Average annual growth rates of hydropower capacity, 1925–61*

[In percent]

Period	Federal	Non-Federal	Total
1946 to 1958	9.7	3.1	5.5
1935 to 1945	34.9	1.1	4.3
1925 to 1958	13.7	2.7	4.5
1958 to 1961	4.5	10.7	8.0

By and large, the Federal and non-Federal sectors of hydro development reflect the purpose for which the individual projects are undertaken. Simply stated, otherwise uneconomic hydro—as viewed by private enterprise—may acquire parity with or even an advantage over thermal power when it is a byproduct or coproduct of flood control, irrigation, and navigation works. The nature of multipurpose stream development, embodying one or more of these nonpower purposes, necessitates governmental participation if not wholly governmental action. With the possible exception of nuclear power, nowhere in the field of energy resources and use is government policy (other than taxation and utility-type regulation) more directly a determinant of the course of events. One cannot, therefore, approach the question of the future level of hydro capacity without making some assumption as to the nature of Federal policy and the extent of Federal participation in hydro development. It may be reasonably inferred from the estimates in table I that with the exception of those in the Government agencies concerned, the authors unanimously assume not only a reduction in the pace of Federal hydro development from that over the past 30 years but also a further reduction below the already much reduced rate that will obtain in the next few years.

Since the implication of a lower rate of growth in Federal hydro in the future is nowhere stated or discussed as such in the context in which the estimates of table I originally appear, it is not possible to determine to what degree the authors were consciously making such an assumption. On the other hand, several of the estimates were associated with statements implying or explicitly noting either economic or physical limitations, or both, on further development of hydro capacity in the coming decade or two. Column (h) of table I lists the estimates as percentages of the FPC estimate of 118.1 million kilowatts of total hydro potential in terms of installed capacity. On this basis only the Coal Age estimates take development beyond roughly one-half the stated potential.

It is, of course, impossible to determine even roughly the level of hydro development at which economic and physical limitations would force the pace of further development below that of the present. But there would seem to be no a priori reason why such limitations should become effective at or below the level of one-half the potential. Nor should it be forgotten that by limiting the coverage to what is now economic or is expected to be economic the FPC understates the true potential (whatever it may be), so that all the estimates are overstated in column (h) of table I.

The foregoing applies to a consideration of the national hydro picture as a whole. But the regional variation in hydro resources cannot be wholly ignored. Like any natural resource the occurrence of hydropower potential is, by human standards, fortuitous and haphazard, with high concentrations in certain relatively restricted regions and relative scarcity in others. This is illustrated in table III, which compares the regional occurrence of hydro potential according to the FPC and Geological Survey estimates. Although specific percentages by region differ in the two reports the wide regional variability is demonstrated in both, and they agree in the identification of the regions in order of concentration.

TABLE III.—*Regional distribution of U.S. hydropower potential*

[Percent of total potential in each region]

Region	FPC		USGS, 90 percent availability [1]	USGS, 50 percent availability
	1953	1958		
New England	4	4	2	3
Middle Atlantic	7	8	10	10
East North Central	4	3	2	3
West North Central	6	6	4	4
South Atlantic	11	10	6	7
East South Central	7	6	6	7
West South Central	4	4	2	2
Mountain	23	21	26	23
Pacific	34	37	41	42

[1] With storage.

Sources: L. L. Young, "Developed and Potential Waterpower of the United States and Other Countries of the World," December 1954, U.S. Geological Survey Circular 367 (Washington, Government Printing Office, 1955). Federal Power Commission, "Hydroelectric Power Resources of the United States, Developed and Undeveloped, 1953" (Washington, 1953). F. L. Weaver, "Hydro Potentialities as Indicated by the Federal Power Commission," paper presented at the Twenty-first Annual Meeting, American Power Conference, Chicago, Apr. 1, 1959. (The earlier FPC data are included so as to make the dates of the agencies' estimates more comparable.)

The pace of development in different regions is certain to vary, determined not only by the endowment of hydropower resources but also by the general complex of regional economic growth. Thus different rates of hydro development in the past have resulted in different present levels of exploitation of the hydro potential in the several regions of the country. The FPC shows the current regional status, in terms of its own resource estimates, as follows:[44]

Region:	*Percentage development of hydro resources*
New England	36
Middle Atlantic	16
East North Central	25
West North Central	18
South Atlantic	33
East South Central	50
West South Central	20
Mountain	15
Pacific	23
United States as a whole	24

Taken by river basins the percentage of exploitation in 1957 ranged from a high of 92 percent for the Tennessee to a low of 2 percent for the Potomac.[45] The future pace of development will also depend, therefore, on the level of exploitation that has already been reached. Other things being equal, a high exploitation level would imply a relatively slow future development rate. For the country as a whole it is significant that the regions with the greatest concentration of resources are relatively little developed.

TECHNOLOGY AS A DETERMINANT OF FUTURE HYDROPOWER DEVELOPMENT

Technology, as manifest in technological progress, is both an "external" and "internal" determinant of the pace of hydropower development. It is external in the sense that the technology of other water use or management, such as for irrigation, navigation, flood control, and the various consumptive uses of industry, affects the pace of hydro development. Improved irrigation techniques will, for example, through multipurpose projects, stimulate associated hydropower development. The feasibility of the St. Lawrence Seaway made possible the current construction of the associated power facilities. But these aspects are outside the scope of the present study, which can do no more than acknowledge them.

Technology as an internal determinant concerns the various aspects of hydropower proper already noted in the introduction—the design, construction, and operation of dams, equipment, and facilities, and the transmission of the generated power. It is an internal determinant in two ways: through the extension of the margin of technical feasibility, or practicability (i.e., the "creation" of a larger technical potential); and through lowering the costs of new hydropower, in constant dollar terms (i.e., an enlargement of the economic potential at any given time by intensive marginal development). The former is a straightforward matter of technology, but the latter, involving costs, requires consideration of the competitive position of hydropower as an energy source.

Superficially, the position of hydro versus thermal power in the continuing expansion of electric generating capacity can be viewed as an equilibrium arrived at and maintained by competition at the margin. Such competition in the past has resulted, according to this view, in the more or less complete development of the economic potential. Growth in the future will then be the result of a comparison of the power cost at each undeveloped hydro site with the alternative thermal plant that could be built. It has been stated, for example, that the undeveloped portion of what is here termed the technical potential can be developed "any time that the price of fuel makes the hydro competitive with the steam station for lower load factor. The reason no more hydro plants have been built (than already exist) is that * * * the initial investment is much higher than that for a steamplant, enough so that unless the load factor exceeds 65 percent or so, the hydro total costs (operating and fixed charges) exceed those of a steamplant." [46]

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[44] Weaver, op. cit.

[45] Federal Power Commission, "Hydroelectric Power Resources of the United States: Developed and Undeveloped, 1957," p. 195.

This view is also expressed in the following argument that hydro has been saved from limbo in this country during the past period of large increase in thermal plant efficiency only by rising fuel costs.

> Of course, this does not mean that waterpower is immune to cost increases; for it, too, is afflicted with higher cost. But the point here is that the particular technological advancement whereby fuel electricity was to give hydroelectricity the coup de grace is not proving quite so powerful because its force has been blunted by the rising cost of fuel which overcompensates the savings.
>
> In this connection, one must keep in mind that, temporarily at least, the rapidly increasing use of natural gas * * * is injecting a new factor into the competitive struggle between diverse sources of energy and may offset here and there the benefits that otherwise might accrue to hydroelectricity as a result of the rising prices of coal and oil.[47]

But this view is an oversimplification that ignores the multipurpose basis of a large portion of recent and current additions to hydro capacity. As part of a multipurpose project, hydro capacity cannot be compared directly with alternative thermal capacity in simple cost terms (see p. 67, above). Direct comparison, moreover, carries the implication that the hydro capacity in question is, like the alternative thermal capacity, capable of supplying continuous power at a rate approximating the installed capacity. But this is not necessarily true:

> * * * in general, hydroelectric projects are best suited for operation at low capacity factors in the peak portions of area and regional loads. The relatively simple and rugged construction, with operations at low speeds and temperatures, and the quick-starting ability make hydro projects adaptable for such peaking and reserve uses. Projects with ample pondage or with reservoir storage capacity are particularly valuable for such purposes. It is for such uses, therefore, that hydroelectric power derives its greatest value and provides its most valuable contribution toward meeting power demands. It may be noted that hydroelectric operation at low capacity factors results in the minimum possible conflicts with increasing consumptive uses of water.[48]

Nor is this merely a hypothetical consideration:

> With rapidly increasing powerloads in the United States, hydroelectric plants are being used to a greater extent in providing system reserves and in carrying short-time peakloads supplementing the baseload generation provided by fuel-electric plants. The hydroelectric plants, with limited amounts of energy available, *are designed to include large installed capacities to carry substantial portions of the peaks in the loads* * * *
>
> Even in the Pacific Northwest where today hydroelectric plants supply the bulk of the entire powerloads and where until recently feasible hydroelectric power appeared to be available in such large potential quantities as to obviate the need for appreciable amounts of fuel-electric capacity, the long-range thinking and planning are in the direction of ultimately considering hydroelectric power for peaking as well as for baseload purposes in conjunction with fuel-electric sources of power supply.[49] [Italics added.]

Thus it is particularly important, in attempting to estimate future installed capacity, not to identify hydro capacity in general with continuous power:

> The evaluation of this resource must be on some basis other than the firm power that can be developed under minimum flows of the rivers. The factors of secondary usage and of coordination with other sources of electric energy represent the greatest means of applying technological knowledge to extend the resources of hydroelectric development.
>
> Many existing projects can be redeveloped or enlarged to overcapacity for the stream; but such plants can be counted on only when coordinated programs of interconnection and operation are utilized.[50]

Although the direct cost comparison of hydro and thermal is not the only or necessarily the major determinant of whether a given hydro possibility is economically justified, this is not to say that hydro costs per se can be ignored. If they must be considered, then in the present context the crucial question is whether, in fact, hydro costs are subject to a secular increase, as the foregoing quotation from Zimmermann states. It should be noted that at least one authoritative source, the President's Materials Policy Commission, shares this belief:

> A few large water power sites remain to be developed which will produce low-cost power, but the remaining sites will require a higher capital outlay per unit of output and other expenses to be able to deliver electricity at the same low cost. As a consequence, the costs of hydropower also are subject, on an average, to upward pressures.[51]

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[46] Pigott, loc. cit.

[47] E. W. Zimmerman, "World Resources and Industries" (New York: Harper, 1951, rev. ed.), p. 571.

[48] F. L. Weaver, "Prospects for Future Hydroelectric Development in the United States and What It Is Likely to Cost," "Prospects for Nuclear Power" (New York: National Industrial Conference Board, 1957). See also F. A. Allner, "Economic Aspects of Water Power," "Transactions," American Institute of Electrical Engineers, vol. 52, No. 1, March 1933, pp. 156-166.

[49] F. L. Weaver and G. G. Adkins, "Hydroelectric Power Development in the United States," paper 64 A/15, Fifth World Power Conference, Vienna, June 1956.

[50] S. L. Kerr, "Role of Technology in the Future of Hydroelectric Power," Battelle Memorial Institute (unpublished) report to the President's Materials Policy Commission, Oct. 1, 1951, p. 1.

[51] P.M.P.C., op. cit., vol. I, p. 117.

To the extent that the lower cost hydro sites tend to be developed first, the tenor of the Commission's argument cannot be disputed. Whether it is too broad a generalization is less significant, however, than the fact that the argument ignores or denies the possibilities of future technological progress. The Commission acknowledges this possibility in a manner of speaking a page or so later in noting the opportunities for reducing capital outlay through better construction technology and the "avoidance of the kind of 'overdesign' and 'overbuilding' which has characterized some hydropower structures in past years." [52] Conceivably, technologic advance in the design, construction, and operation of hydroelectric stations should considerably offset the general rise of marginal development costs with time and could even yield cost advantages for a significant portion of the undeveloped hydro potential. A study of European experience demonstrates that this has, in fact, occurred in that region in the past and may continue to hold in the future.[53] The purpose of this section is to ascertain whether, in this country, it is reasonable to expect that technology in the coming decade or two will be able to hold the line against the secular upward pressure on hydro costs owing to the exploitation of progressively more expensive sites.

Design and construction

Since the major element in the cost of most hydropower installations is the dam, it is especially significant in the present context that the United States has been lagging behind other countries of the world in at least one aspect of dam technology. For a period this country placed major reliance on the concrete gravity dam, which utilizes the sheer weight of the concrete mass to hold back the impounded water. Because of the large volume of processed materials that goes into such a dam it is not necessarily the most economical type of structure in all circumstances. (Note also the reference to "overdesign" by the President's Materials Policy Commission on p. 78 above.) Recently there has been a tendency in this country to make more use of earth and rockfill dams, which realize the benefits of modern earthmoving technology, but there is some evidence that the arch dam has been unduly neglected in the recent past in this country, at least in the bold exploitation of its possibilities, while its use has been pushed aggressively abroad.[54] To the extent that this is true there is the possibility that consideration of arch dams for specific hydro sites could make otherwise uneconomic projects economic [55] and could result in a larger total developed capacity at any given time.

In addition to major cost savings that can be expected through the full exploitation of modern design possibilities in dams, it is reasonable to anticipate further, modest savings from wider application (and continued further development) of present techniques of underground rock excavation. More and longer tunnels will mean more efficient use of hydro sites that would otherwise require more expensive structures and facilities. Similar benefits should accrue from the wider use of underground structures for turbines, transformers, and switching gear. (The provision of an underground powerhouse, for example, often increases the effective head and eliminates the costs of steel penstocks and surge tanks.) Again, it appears that European development on this score has been preceding development in this country.[56]

Similar opportunities appear to be present in turbine-generator design. Turbine efficiencies, to be sure, are already so high that there is little room for major improvement.[57] Nevertheless there is still ample scope for increasing the heads with which each of the types can be used. The use of Kaplan and Francis types in the upper range of the heads for which they are adapted permits the use of turbine designs allowing the highest speed of waterflow, higher turbine speed, a smaller size turbine and generator, and smaller station size, thus yielding improved overall efficiency and lower costs.[58]

Another aspect of technological advance in this field is the recent European development of the "bulb," or immersed Kaplan turbine, which operates horizontally under a very low head.[59] This should serve to extend the lower limit of economical hydro developments (in terms of low heads and smaller power potential), in what has been termed "micropower plants," to complement progress at the intensive margin of development made possible by the previously mentioned advances.

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[52] Ibid., pp. 119f.

[53] Economic Commission for Europe, op. cit., pp. 15-29.

[54] See editorial, Engineering News-Record, Apr. 12, 1956, and reader comment thereon, May 17, 1956 and June 28, 1956; also the issues of Feb. 21, 1957, and Sept. 11, 1958.

[55] See, for example, Engineering News-Record, June 14, 1956.

[56] Cf. Doland, op. cit., p. 36.

[57] Current top turbine efficiencies are 93 percent for the Kaplan type, 92 percent for the Francis type, and 92 percent of the Pelton wheel.

[58] E. R. DeLuccia and F. L. Weaver, "The State of Hydro-Electric Power Development in the United States," Transactions, Fourth World Power Conference, 1950, vol. IV, p. 2090.

In the opinion of at least one observer there is also a technological lag in turbine design in this country similar to that cited above with respect to the application of arch dams:

> The nature of the hydraulic turbine industry is such that the design of the full-size units is based on model tests in research laboratories, and the performance guarantees of the manufacturers are predicated on the results of such work. The coordination of research and full-scale performance is essential to the progress of the industry. In the last 10 to 15 years, the performance testing of completed installations has been meager, and as a result, there is the same lag in technological progress that existed prior to 1918, at which time precise methods of water measurement became available to check the performance guarantees of hydraulic turbines.
>
> The technical developments in the United States as related to hydraulic turbine design thus have a major effect on the future scope of hydroelectric power as a national resource.[60]

Kerr cites two instances of this alleged lag: "In general, the range of specific speeds available for various heads from manufacturers in the United States is lower than offered in the world market, and this in turn makes the equipment more costly;" and "elsewhere in the world the vertical-shaft types [of turbine] with multiple jets have been in successful operation and many years with efficiencies and satisfactory performance far beyond anything found in the United States."[61]

One does not need to infer from these statements that great opportunities exist here for enlarging the economic potential or for significantly accelerating the pace of hydro development. But to the extent that such a situation may prevail, the opportunities are present for higher efficiencies, hence lower costs in future hydro installations.

Operation

It was observed above that the proper consideration of hydropower must include its place in electric power systems, where it may be integrated with other power sources. Under such circumstances hydropower may be used for either baseload or peakload purposes. A special technique of using hydro for the latter purpose is the method known as pumped storage. This consists in the use of off peak power available from a given system to pump water uphill into a reservoir, from which it can be drawn to generate hydropower to augment the system capacity under peakload conditions.

The principle of pumped storage has been known and used for over half a century in Europe, where there are currently about 100 installations. In this country, however, there was only one pumped-storage plant prior to 1950. In that year the reversible pump-turbine was brought out, constituting a basically new idea in hydropower, and the pumped-storage approach received a worldwide stimulus. This development significantly reduced capital costs for pumped storage and at the same time raised operating efficiency. The technique thus became an immediately competitive alternative in planning additions to system capacity. By 1956 there were four pumped-storage installations in the United States and others existed in planning stages in all regions of the country.

The importance of this development warrants a brief survey of the advantages and opportunities it offers. In terms of cost advantage, it is the conclusion of one study that, allowing for "reasonable load-factor operation," pumped storage can sustain initial investment costs of up to $25 per kilowatt more than the average cost of steam capacity.[62] (And, to the extent that investment costs for pumped storage are not greater than alternative steam capacity, the result can be net savings.) This is possible because of such advantages as:

1. Large reactive capacity available for system voltage regulation.
2. Almost zero cost of spinning reserve.
3. Relatively rapid load pickup or load drop.
4. Location of powerplant where steamplant would be impractical, and in plant sizes that would be uneconomical for steam.

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[59] See H. Chamayou, "Le groupe prototype de Castet et les perspectives d'avenir qu'il ouvre dans l'equipment hydroelectrique," paper 97 II/17, Fifth World Power Conference.

[60] Kerr, op. cit., p. 2.

[61] Ibid., pp. 3 and 5.

[62] E. S. Loane, "Pumped-Storage Hydro Attractive," Electrical World, vol. 148, No. 13, Sept. 23, 1957, p. 73.

5. Use of smaller generating units, providing better opportunity for fitting capacity to load.

6. Relatively short leadtime for additions to capacity of a developed site.[63]

These general advantages are supplemented by others that are determined by the type of system to which pumped storage is being added. The technique can be used on a limited scale at some hydro site to add flexibility to the operation of the reservoir.

> To be most economically attractive such pumping has to be applied to a scheme designed for low load factor with restricted upper storage but preferably a large tail reservoir. * * * Besides offering opportunities for maintaining reservoir levels in times of drought, and hence maintaining the kilowatt capacity at a higher firm figure, pumping may enable a higher average reservoir level to be achieved with consequent increased output. Alternatively, the pumping can be applied to enable the same results to be obtained with a lower dam.[64]

The need for only a small upper reservoir, moreover, "permits use of pumped storage in places entirely unsuitable for the usual hydroplant. This flexibility of location should allow other economies through use of shorter penstocks or tunnels and proximity to transmission." [65]

With respect to the integration of pumped storage with steam capacity, the basic usefulness of the former stems from the desirability of providing as high a plant factor as possible for new steamplants. As the trend continues toward the construction of larger steam units employing more advanced technology, the high efficiency of these units yields incremental energy at low cost. Hence it is desirable to get as much of the system supply as possible out of such units. The pumped-storage technique helps to accomplish this by offering a means of storing surplus, offpeak, low-cost energy in a reservoir for release on peak. Since there are losses in pumping and regeneration there must be other advantages, such as low capital costs, as compared with alternative new steam capacity, to offset these losses. Moreover, the effect of adding pumped storage to a steamplant system for peaking purposes is to increase fuel consumption in the system,[66] since the fuel requirements of existing steam capacity to power the pumps would be greater than the fuel requirements of new steam capacity equivalent to the pumped-storage capacity. This leads to the paradoxical conclusion that pumped storage may be more advantageous in low-cost fuel areas.

The situation concerning the future possibilities of integrating pumped storage with nuclear powerplants is analogous to that of the advanced steam technology (assuming economic nuclear power to begin with). Again, units are large, capital costs are high, incremental generation cost is low, and the desirability of a high plant factor is accordingly enhanced. Not only are the possibilities on this score recognized, but at least one pumped storage-nuclear combination is already projected in Great Britain.[67]

The evidence, in short, indicates strongly that pumped storage with reversible pump turbines is a technological development in hydropower of the greatest importance, for pumped storage can create hydro capacity at sites where no natural flow exists. Conventional thermal plants are often located at or near a stream or lake for transportation advantages and cooling purposes. "It is conceivable that utilities with conventional lakeshore or riverside thermal generation plants in hilly regions might construct artificial reservoirs for pumped-storage systems to gain extra peakload generating capacity in the not too distant future." [68]

This raises the question of whether pumped storage really constitutes hydropower. The latter term usually implies free energy—energy realized from natural precipitation. Pumped storage, on the other hand, is a means of storing energy that may be derived from other sources than hydro, for use at a more convenient time. If pumped storage is not hydro, it bears no relation to the hydro potential at any level, and must be considered separately. It is easy to get involved in a semantic snarl here, but it would appear that there is far more to be gained in simplicity of concepts and terminology by bringing pumped storage within the concept of hydro than by consigning it to its own category; for pumped storage, after all, does produce electricity from falling water, with the same equipment and technique used in hydro, regardless of the fact that it was human ingenuity rather than natural processes that raised the water to a position from which it could fall.

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[63] Ibid., p. 77. The pumped-storage installation at the Sir Adam Beck station on the Canadian side of Niagara Falls had a slightly lower capital cost than equivalent thermal capacity. (O. Holden, "Three Pump-Turbines in Operation," Electrical World, Jan. 20, 1958, p. 57.)

[64] A. A. Fulton, T. G. N. Haldane, and R. W. Mountain, "The Practical Application and Economics of Pumped Storage in Great Britain," paper 227 II/38, Fifth World Power Conference.

[65] Loane, op. cit., p. 75.

[66] Ibid., p. 77.

[67] "Nuclear Power," vol. 2, No. 15, July 1957, p. 264; Atom, No. 11, September 1957, p. 14; J. M. Kay and A. A. Fulton, "Combined Use of Nuclear Power and Pumped-Storage Hydro Stations" (Paper 15/P/1448, Second United Nations International Conference on the Peaceful Uses of Atomic Energy, Geneva, September 1958).

[68] W. J. Rheingans, F. Jaski and H. H. Roth, "Pumped Storage," proceedings, Midwest Power Conference, vol. XIII, 1951, p. 154. (Indeed, a project is already being considered that would put a pumped-storage plant on the shore of Lake Erie and form a reservoir by damming both ends of a nearby valley in the Allegheny Mountains. See Power Engineering, vol. 60, No. 3, March 1956, p. 105.)

Accordingly, for the purposes of this discussion pumped storage is considered to come under hydropower, but in so doing the effect of this definition on the hydro potentials concepts must be acknowledged. Since pumped storage can "create" hydro potential where none exists in nature, this must be allowed for in the theoretical potential, the scope of which should be enlarged to this extent. Similarly, the technical and economic potentials should be raised by the inclusion of pumped storage, and any estimate of future installed hydrocapacity should reflect this consideration. One writer has concluded that "in general, a system without other hydro capacity might utilize pumped storage to the extent of 10 to 15 percent of total system capacity." [69] and there is already a widespread appreciation of the probable rapid growth of pumped storage in integrated systems.[70]

Transmission

The relation between line voltage and transmission costs is inverse, and between line voltage and maximum distance is direct; that is, higher voltage is economically justified with larger blocks of power and longer distances. The significance of this with respect to hydropower concerns large, remote hydro sites, and to a lesser extent all hydro sites. Since higher voltages make possible transmission of electric power over longer distances, the economic potential of hydro resources is affected; and to the extent that higher voltage contributes to more interconnection of power systems, the development of hydro in general is affected (it was brought out above that otherwise uneconomic hydro sites may be economic if considered as part of an integrated system). Current transmission technology in this country utilizes a maximum of 345 kilovolts, with an economic limit of 200 to 300 miles in distance. (Voltage up to this level is known as high voltage; higher levels are often referred to as extra high voltage (EHV).)

The importance of future progress in transmission technology in the present context is indicated by the fact that if a distance of 600 miles for power transmission were to become both technically and economically feasible in this country there would be sufficient radius for interconnections over the entire Nation, and every hydro site would be within range of existing markets (although not every site, to be sure, would thereby automatically become economic). This distance is possible with the utilization of 500 kilovolts. An example of the specific effects of this achievement on the hydro potential is given by a study of the Bureau of Reclamation which analyzes the possibilities of employing 500 kilovolts on a grand scale in the United States west of the Mississippi River. According to the Bureau's analysis a supergrid for the 22 Western States, tying in the source regions of hydro and coal-based steam power, would make feasible and economic by 1975 the development of almost two-thirds of the hydro potential of the area as a whole (as given by the FPC). This constitutes some three-quarters of the national potential as estimated by the FPC at the time.[71]

It is not necessary here to judge the practicality of the Bureau's scheme [72] since it does not matter whether the scheme as proposed is realistic. For the purposes of this study the Bureau's analysis suggests the possible magnitude of the effects of ehv on hydro development. The question then is, what degree of progress can be reasonably expected in the period under consideration?

Published opinion is divided on this question. According to the most pessimistic view:

> A great increase in the economic distance of electric-power transmission does not seem to be in the cards. To get it by pushing the voltage up much above the present maximum of 287 kilovolts, where it has been for nearly 20 years, does not seem likely. There is no foreseeable prospect for transmission lines operating in this country above about 315 kilovolts and certainly not above 380 kilovolts.
>
> * * * The fact is, the energy of our rivers will likely continue to be used within 200 or 300 miles—and mostly

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[69] Loane, op. cit., p. 73.

[70] See, for example, Grzywienski, loc. cit., Weaver, loc. cit., and "Symposium on Pumped Storage," Proceedings, American Power Conference, vol. 20, 1958, pp. 385–417.

[71] Bureau of Reclamation, "A Study of Future Power Transmission for the West," Washington, 1952.

[72] For an opinion on this score see Business Week, Jan. 3, 1953, p. 34.

less—of its generation. History has shown that where low-cost power is, there energy-consuming industries go.[73]

A less extreme, but on the whole pessimistic view is expressed by others. One discussion concludes that the advantages of ehv in long bulk transmission may be less than in superimposing it within existing systems because of the possibilities offered by greater development at existing voltages, particularly if this is 230,000 volts or above.[74] Another study compares the cost of fuel transport with the transmission of blocks of power up to 3.6 million kilowatts and voltages up to 460 kilovolts, for distances up to 700 miles. It notes that large power blocks combined with high load-factor loads tend to make fuel and electric power movement competitive, the balancing economies being determined by freight costs and the financing costs of transmission lines.

> Primarily because of the cost of getting the coal off and on wheels * * * electric transmission is far cheaper for short distances but more expensive as distance increases. The break-even point depends primarily on the capital charges on the investment and on the block of power being transmitted. Even when handling 1,800,000 kilowatts the break-even point under American conditions is only * * * [160 miles] when total capital charges are 14 percent and * * * [425] miles when they are 10 percent. For really long distances, transmission of electric power is uncompetitive.[75]

Recent events, however, suggest that these opinions are in error, or at least that they seriously underestimate the possibilities of ehv and the imminence of its use. An experimental 500 kilovolt line is currently under test in the Colorado Rockies, and in June 1958 plans were announced for a 5-year research program (titled "Project EHV") to advance knowledge of ehv transmission and to gain actual operating experience in the ranges of 460 to 750 kilovolts. Operation at 460 to 500 kilovolts is scheduled to take place in 1960. In the following year the voltage will be raised to the 600 to 750-kilovolt range; and in 1963 results of the tests will be evaluated to determine whether they should be continued at 1,000 kilovolts. Of special significance to the present discussion is the prediction of the project director that there will be eventually in the United States a transcontinental power grid that will interconnect all major power generating areas of the country.[76]

Project EHV is described by its undertakers as helping to reestablish the United States as a world leader in ehv technology. Considering the relative abundance of low-cost fuels in most parts of this country it is not surprising that it is not the most advanced in ehv technology. A 400-kilovolt network involving a distance of 300 to 400 miles has been in service in Sweden since 1952, and the Soviet Union placed a similar transmission system in service in 1956 over a distance of 505 miles. This reflects a strong incentive in both countries to explore this avenue of development because of their power resource position. Both have large hydro resources located long distances from consuming centers where fuel costs are high. Swedish engineers anticipate the need to transmit power over 500-mile distances by 1980, are prepared to use 500 kilovolts, and believe that 650 kilovolts can be controlled with current technical means.[77] Their Soviet counterparts intend to raise their 400-kilovolt system to 500 kilovolts, and believe it is technically possible to extend transmission at such voltages to distances up to 2,000 miles.[78]

At such voltages and distances, however, the economic transmission of large blocks of power using direct current becomes competitive with the traditional alternating current. Again, the lack of incentive in this country has caused direct current transmission to be largely ignored, but in Sweden and the U.S.S.R. research has been going on for some time. At the research level the two countries appear to be about even, but the Soviets have begun construction work on a truly grandiose scheme for an 800-kilovolt, 340-mile, direct-current line between Stalingrad and the Donbas, planned for 1960, which would provide the experience for designing and operating a direct-current line at 1,000 kilovolts tying the hydro resources of far Siberia into various consuming centers.[79]

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[73] Ayres and Scarlott, op. cit., pp. 251f.

[74] V. M. Marquis and H. P. St. Clair, "Transmission Looks to the Future," Electrical World, vol. 133, No. 21, May 22, 1950, pp. 115-117.

[75] C. N. Phillips, "Economics and Developments to Expect in Transporting Energy," Bulletin, Edison Electric Institute, vol. 21, No. 7, July 1953, pp. 271-276. Cf. also the more recent paper by J. K. Dillard and M. Maxwell, "Economics of Extra-High-Voltage Transmission," (Paper 40 D/10) World Power Conference Sectional Meeting, Montreal, Sept. 7-11, 1958.

[76] Electrical World, vol. 149, No. 23, June 9, 1958, pp. 54, 55, 58. In the same vein, two General Electric engineers have predicted 650 kilovolts will be in use in this country in 1977. (American Metal Market, Feb. 5, 1959.)

[77] Gunnar Jancke, "High Tension Transmission Problems With Special Reference to the Swedish Network," Proceedings, American Power Conference, vol. XIX, Chicago, Illinois Institute of Technology, pp. 422-434.

[78] J. H. M. Sykes, "Soviet Transmission Features," Electrical World, vol. 148, No. 14, Sept. 30, 1957, pp. 64f.

[79] Ibid., passim.

The specific Soviet intentions may be discounted for overconfidence, but the fact remains that in the period through 1975 ehv technology and operating experience with both a.c. and d.c. are likely to exist in Sweden and the U.S.S.R. The fundamental fuel-cost advantage of this country can be assumed to continue throughout the period, hence there is no reason to suppose a wholesale swing in the United States to the most advanced ehv technology in Europe.[80] At the same time, it can also be reasonable assumed that experience and continued research with ehv in Europe will reduce its costs in general, so that it would seem unwise to rule out the possible effects of ehv on the pace of future hydro development in this country. The technology will be available if economic opportunities appear for its use. The first paragraph of the quotation from Ayres and Scarlott, above, page 81, was obsolete almost as it was being written; the Bureau of Reclamation's visionary scheme is at present fully as plausible as the second paragraph of that quotation.

Small powersites

There remains one aspect of the impact of technology on the pace of hydro development that partakes of the benefits of advance in most, if not all of the field of technology surveyed above. It will be recalled that the estimates of potential hydropower by both the FPC and the Geological Survey exclude small sites of less than 2,500-kilowatt capacity. The President's Materials Policy Commission noted that at the time of its investigations more than 1,000 potential hydrosites, mostly relatively small ones, "were apparently not receiving serious attention by anyone," but shared the consensus that they were of little import in that "many of these may upon closer examination not prove economically feasible to develop by 1975." [81]

Clearly the significance of small sites is not very great in the total hydropower picture even if most of them are economically feasible. Assuming that the average potential capacity of the sites is 1,250 kilowatts, or one-half of the upper limit with which they have been defined, the total capacity of the 1,000 sites would be on the order of 1,250,000 kilowatts. Although this is equivalent to only one very large hydro development the contribution should not necessarily be ignored. It is likely that the regional distribution of these small sites is as variable as is that of hydro capacity in general, hence in certain regions the "small potential" could be not wholly insignificant.

There is, moreover, some evidence that a good portion of the potential is economic at present. Between 1948 and 1953, for example, a power company in North Carolina constructed five small plants ranging in size from 1,800 to 12,000 kilovolt-amperes. The company considered the sites economically attractive in the light of three developments: (1) recent advances in supervisory control and telemetering equipment, allowing fully automatic operation by remote control, (2) advances in turbine construction reducing required maintenance, and (3) the use of rock-fill dams, which cost less than one-twelfth the cost of concrete per unit volume and which have many other engineering advantages at small sites. On the basis of its experience the company believes that "there still remains economically hydroelectric potential in many of the smaller streams which are more commonly available." [82]

This suggests that expected future progress in all areas of technology considered above save EHV transmission should tend to increase the economic potential of small sites. To this extent, existing resource estimates and estimates of future installed capacity all tend to understate the true possibilities.

CONCLUSIONS

The hydropower potential of the United States

The discussion of the Government estimates of U.S. hydro resources earlier in this study ended on a censorious note—the existing estimates are mislabeled, their coverage is incomplete, and they are ambiguous. But this does not mean they lack any validity whatsoever; they do constitute in some fashion a measurement of this country's hydro resources. The problem is to interpret them within the concepts employed in this study.

Young's estimate of 86 million kilowatts as the hydro resources at mean flow was judged to be somewhere between the theoretical and technical potential in concept and something less than the technical potential in coverage. Conceptually, the estimate can be brought closer to the technical potential by replacing its assumptions of 100 percent efficiency and gross head with a factor that corresponds to current technological capability. A figure of 70 percent would appear to be reasonable and conservative for this purpose.[83] On this basis the survey figure becomes approximately 60 million kilowatts.

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[80] Although the potentialities in high-capacity, low-cost transmission from coal fields to load centers could lead to the mutual stimulation of EHV and mine-mouth power generation.

[81] President's Materials Policy Commission, op. cit., vol. III, p. 37.

[82] H. H. Gnuse, Jr., "Small Hydro Sites Can Be Developed Economically," Electrical World, vol. 140, No. 10, Sept. 7, 1953, p. 80.

The significance of this figure should be carefully understood. It can best be described as the closest currently possible approximation to the technical potential of this country. When used as such, moreover, it means that the technical potential is at least 60 million kilowatts. Its error is all on the low side due to the understatement that results from the incomplete coverage in the measurement procedure (and perhaps also on the score of a conservative efficiency factor). As a minimum figure it therefore has considerable value.

The Federal Power Commission estimate of 118 million kilowatts installed and installable capacity as the hydro resources of the United States was put somewhere between the technical and economic potentials in concept and below the latter in coverage. The only way to make this figure consistent with the "potentials" terminology is to convert its associated generation estimate to the "comparative capacity" equivalent employed by the Economic Commission for Europe. (See above, p. 67.) Dividing the annual generation estimate of 509.8 billion kilowatt-hours (that accompanies the capacity estimate) by 8,760 yields a figure of 58.2 million kilowatts. Again, as an approximation of the economic potential it is a minimum figure because of the conservatism inherent in the individual site estimates, and the exclusion of pumped storage possibilities. The latter may well be a serious deficiency.

It will be seen that the approximations of economic and technical potential obtained here are surprisingly close together. One would not expect, a priori, that costs would make little difference between what is technically feasible and what is economically feasible. Perhaps this is indeed the situation, but it is in any event clear that the closeness is to some unmeasurable degree a reflection of the human factor. As pointed out previously (see p. 67, above), the innate caution of the engineer-estimator will tend to make him infuse economic criteria into his view of the technical possibilities of a given site. Indeed, this closeness is exhibited to the same degree in European estimates of economic and technical potential.[84]

It would be highly desirable to have the third approximation of theoretical potential, to round out this very rough assessment of the U.S. hydro potentials at all levels. Unfortunately, there is no published figure extant that could be manipulated in a meaningful fashion to yield even a crude idea of what the theoretical potential of this country might be. The Economic Commission for Europe has made an exhaustive statistical analysis of the estimates for the river basins and countries of Europe at the various levels, and has obtained general relationships between the potentials. It concludes, for example, that existing national estimates of economic potential in Europe "in large areas comprising a wide range of natural conditions" are between 15 and 25 percent of the gross potential.[85] Less sweeping, hence more meaningful generalizations, can be made based on these relations as a function of the "density" of the theoretical potential (i.e., kilowatt per square kilometer). It would be interesting to have such density data for this country to test the results by region. In their absence the most that can be done is to speculate on the indicated theoretical gross potential if the relationships were the same in this country as in Europe. Using the above percentages the results are a range of 230 to 380 million kilowatts. Is the theoretical potential of the United States on this general level? In the absence of an adequate basis on which to reach any conclusion the question is left unanswered for this study.

The figures do, however, suggest that the hydro resources of the United States, when viewed in the appropriate perspective, are appreciably larger than has heretofore been realized. The significance of this conclusion is emphasized by comparing current capacity with the approximate economic and technical potentials. The 1958 (year-end) installed capacity of some 30 million kilowatts generated 143 billion kilowatt-hours; converting the latter into a "comparative capacity" figure yields 16.3 million kilowatts. On this basis current capacity constitutes at the most between one-quarter and one-third of the actual economic and technical potentials. Or, to put it in terms of possibilities, available data suggest that the hydro resources of this country that can be economically developed at present are perhaps on the order of four times the current level of development. With due allowance for the crudeness of these results it is reasonable to conclude that hydro capacity can be greatly expanded without running into serious cost limitations, and that the overall resource limitations on hydro development are not yet within sight.[56] Indeed, the limitations that will effectively brake hydro development in the eventual future will be the competing, consumptive water uses.

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[83] Current overall plant efficiency in this country is given by an authoritative source as 80 to 83 percent based on net head; with gross head the overall figure is 10 to 15 less. (W. P. Creager and J. D. Justin, "Hydroelectric Handbook," New York, Wiley, 2d ed., 1950, p. 160.) The Economic Commission for Europe uses 75 percent for overall efficiency based on European practice (op. cit., p. 62). The Bureau of Reclamation assumes in its preliminary site studies an efficiency of 80 percent, for storage plants and 75 percent for run-of-river plants. (Bureau of Reclamation Manual, vol. IV, ch. 4.2.) Davis uses 80 percent for his Canadian estimate (loc. cit.).

[84] Economic Commission for Europe, op. cit., pp. 84 and 93-95.

[85] Ibid., p. 93.

Installed hydropower capacity in the United States in 1975

The estimates of future installed capacity listed in table I can now be viewed in the light of the survey of technology and the resource conclusions just presented. The implications of the technology survey are that general progress in the technology of hydroelectric design, construction and operation, and of power transmission, should continue to favor the development of hydro resources by counteracting the less favorable physical circumstances of the remaining resources. In particular, the pumped-storage technique enhances the already growing value of hydro as peak capacity and gives promise, with the reversible pump-turbine, of leading to the widespread installation of hydro capacity employing this technique.

None of the estimates in table I, however, is accompanied by any similar statement or implication concerning the influence of technological progress on future hydro development. In the light of the foregoing, the most conspicuous lack is the failure to take account of an indicated rapid growth potential for pumped storage. This suggests that even the higher estimates in the table are not excessively optimistic. (The total, incidentally, of all currently planned additions—including those after 1961—reported in the 1959 Electrical World summary yields a figure of 49.4 million kilowatts, when added to existing capacity as of the end of 1958. This would indicate that, for 1975, all estimates of future installed capacity below this level are unrealistic. Indeed, according to the latest FPC figures for capacity under construction and in various planning stages[57] the total installed and intended to be installed is 57.7 million kilowatts.)

The FPC estimate of 51.7 million kilowatts of installed hydro capacity in 1975 is probably the best substantiated of the estimates for that year in table I, since it is a carefully considered judgment on intended additions to capacity. Nevertheless there is good reason to consider this estimate unduly pessimistic. In the set of estimates of which it is a part the growth rate from 1960 to 1975 is 2.9 percent, based on a 1960 estimate of 33.7 million kilowatts that is 11 percent lower than total existing capacity in 1958 plus currently planned additions through 1961. The Commission, in other words, has been conservative in estimating how much currently planned capacity would actually be installed by 1960, and has assumed a low growth rate from this base.

The former is certainly not grounds for criticism, but the assumed growth rate has disturbing implications when compared with those in table II. It is only one-half of that which has prevailed to date in the postwar period, only three-fifths of that in the previous 20 years and in the past 30 years as a whole, and less than one-third of the growth rate indicated in installations and planned installations in the period 1958–61. The imponderables of politics enter into the matter of Federal power development policy,[58] so that it would be unwarranted to assume that the growth of Federal power would return to the rate of the 1946–58 period. Similarly, it would be unwise to infer any long-run significance from the current high rate of non-Federal power development. But at the same time, there appears to be no justification for assuming that the overall pace would decline to well below past growth rates. This would mean a remarkably abrupt reversal, of which there is no current evidence, in the prevailing attitude toward the development of hydro resources. Rather, it is reasonable to expect a continuation of the current high level of interest in hydro development, under some aegis, whether private, partnership, or public. On balance, then, the FPC estimate would seem to be overly conservative.

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[56] This is consistent with European findings where, despite the pressures of high-cost fuel resources and the consequent higher level of exploitation of hydro resources, "In no European country where significant hydro production is possible has more than one-half of the possible output yet been developed" (Economic Commission for Europe, op. cit., p. 96).

[57] F. L. Weaver, "Hydro Potentialities as Indicated by the Federal Power Commission," paper presented at American Power Conference, Chicago, Apr. 1, 1959.

[58] This does not mean, however, that it is immaterial, from the economic viewpoint, whether power development is under Federal or private auspices. According to Krutilla and Eckstein, private hydropower development entails fixed charges on capital of 10 to 14 percent of the capital investment, whereas the assumed capital charges in Federal project planning are between 3 and 3.5 percent. (J. V. Krutilla and O. Eckstein, "Multiple Purpose River Development" [Baltimore: Johns Hopkins, 1958], chs. IV and VII.) Significantly different cost levels are thus involved.

Accordingly, a figure of 60 million kilowatts is chosen to represent the lower limit to the range of likely installed hydropower capacity in 1975. For comparison purposes, the implied growth rates of this figure are 4.1 percent per annum from 1958 to 1975, and 3.3 percent from 1961 to 1975 (based on currently planned capacity in 1961). (See table II.)

The upper limit should represent the extent to which the adoption of pumped storage expected in this study actually occurs. Systematic quantification of this expectation is impossible, since the effect of the technique is open-ended (i.e., it can create new hydro potential). The best that can be done is to suggest that the probability of extensive adoption of the technique appears strong, and to represent this probability with a figure of 10 million kilowatts. The upper limit to the range of likely installed hydropower capacity adopted as the estimate of this study is therefore 70 million kilowatts. This implies a growth rate of 5.1 percent in the period 1957–75 and 4.5 percent for 1961–75. The choice of 10 million kilowatts as representing an indicated level of pumped storage installation is, of course, merely a reflection of the opinion of this study that the new technique will be widely adopted—widely enough, in fact, to account for almost one-quarter of total hydro-installations between 1957 and 1975.

There remains the comparison of the 1975 installed capacity estimates with the conclusions on hydro resources. The FPC estimate was converted to a "comparative capacity" basis in order to compare it with the Geological Survey estimate, and both were labelled no more than crude approximations of economic and technical potentials, respectively. Assuming the FPC estimate is a useful approximation of the economic potential, it can be compared directly with the 1975 capacity estimates made above. The range of 60 to 70 million thus constitutes 51 to 60 percent of the FPC resource estimate, which is definitely a minimal estimate of the economic potential; hence it is probably correct to suppose that such capacity in 1975 would constitute no more than one-half the present economic potential.

It can be concluded that not only should there be no decline in the pace of hydro development due to resource deficiency in the period through 1975, but that such development should not encounter a secular cost increase. The magnitude of undeveloped hydro resources is relatively large, and will remain so throughout the period. The combination of the wider adoption of known technology and anticipated further advances in technology should largely offset any tendency to cost increase, in constant dollars, that might otherwise appear. If installed hydro capacity does not grow as expected herein it is more likely to be due to the adverse effects of the other growth determinants—governmental policy, the interest rate, and regional growth in demand.